**TUGAS AKHIR – MO 141326**

# ANALISA PENGARUH MATERIAL ABRASIF PADA PROSES *BLASTING* TERHADAP KUALITAS *COATING EPOXY*

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2017

**FINAL PROJECT – MO 141326**

# ANALYSIS OF ABRASIVE MATERIAL EFFECT FOR *BLASTING* PROCESS ON EPOXY COATING QUALITY

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Surabaya
2017

# Analisa Pengaruh Material Abrasif pada Proses *Blasting* Terhadap Kualitas *Coating Epoxy*

**TUGAS AKHIR**

Diajukan untuk Memenuhi Salah Satu Persyaratan Memperoleh Gelar Sarjana Teknik
pada Program Studi S-1 Departemen Teknik Kelautan,
Fakultas Teknologi Kelautan,
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SURABAYA, JULI 2017

# ABSTRAK

ANALISA PENGARUH MATERIAL ABRASIF PADA PROSES *BLASTING* TERHADAP KUALITAS *COATING EPOXY*


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*Coating* merupakan salah satu cara yang efektif untuk melindungi material logam dari korosi. Metode *coating* lebih dominan digunakan pada industri karena lebih mudah dan lebih ekonomis. Namun metode ini juga tak lepas dari berbagai hal yang mempengaruhi kualitas dan efektivitasnya. Proses penyiapan material hingga proses pelapisan selesai sangat menentukan kualitas *coating*. Salah satu proses penyiapan material yang menentukan kualitas *coating* adalah proses pengasaran permukaan. Pada permukaan yang luas biasanya digunakan metode *blasting* untuk membersihkan sekaligus mengasarkan permukaan material. Saat ini tersedia banyak jenis material abrasif yang dapat digunakan untuk proses *blasting*. Penelitian ini dilakukan untuk mengetahui pengaruh material abrasif pada proses *blasting* terhadap kualitas *coating epoxy*. Material dasar berupa pelat ASTM A36 dan A53 di-*blasting* dengan material abrasif *steel grid*, garnet, dan silika. Lalu diukur nilai kekasaran permukaannya. Kemudian diberi *coating epoxy* dengan metode *spray* dan diuji daya lekatnya. Dari pengujian yang dilakukan, didapat hasil bahwa daya lekat meningkat seiring meningkatnya kekasaran permukaan. Material abrasif *steel grid* adalah yang terbaik untuk pelat A36 dengan nilai rata-rata kekasaran permukaan 86,8 μm dan daya lekat rata-rata 11,9 MPa. Sedangkan untuk pelat A53 material abrasif silika adalah yang terbaik dengan nilai rata-rata kekasaran permukaan 86,4 μm dan nilai daya lekat rata-rata 11,3 MPa.



***Kata kunci : coating, blasting, material abrasif***

## *ABSTRACT*

*ANALYSIS OF ABRASIVE MATERIAL EFFECT FOR BLASTING PROCESS ON EPOXY COATING QUALITY*



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*Coating is an effective way to protect metal materials from corrosion. Coating method is more dominant used in industry because it is easier and more economical. But this method also can not be separated from various things that affect the quality and effectiveness. The process of preparing the material until the coating process is completed will determine the quality of the coating. One of the process of preparing the material that determines the quality of the coating is the surface curbing process. On a wide surface is usually used blasting method to clean as well as roughed surface material. Currently available many types of abrasive materials that can be used for the blasting process. This research was conducted to determine the effect of abrasive material on the blasting process on epoxy coating quality. The basic materials of ASTM A36 and A53 plates are blasted with abrasive steel grid, garnet, and silica materials. Then measured the value of surface roughness. Then was given epoxy coating with spray method and tested its stickiness. From the tests conducted, the results obtained that the adhesiveness increases with increasing surface roughness. The steel grid abrasive material is best for A36 plates with an average surface roughness value of 86.8 μm and an average adhesion power of 11.9 MPa. As for the A53 plate the abrasive silica material is the best with an average surface roughness value of 86.4 μm and an average sticking power value of 11.3 MPa.*



***Keywords : coating, blasting, abrasive material***

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Syukur *alhamdulillah* penulis panjatkan atas kehadirat Allah SWT yang telah memberi nikmat sehat, kekuatan, dan kemudahan kepada penulis, sehingga penulis dapat menyelesaikan tugas akhir beserta laporan sesuai waktu yang telah direncanakan.

Tugas akhir berjudul "Analisa Pengaruh Material Abrasif pada Proses *Blasting* Terhadap Kualitas *Coating Epoxy*" membahas dan membandingkan beberapa jenis material abrasif yang dapat menghasilkan kualitas *coating* antikorosi terbaik pada dua material. Tugas akhir ini disusun untuk memenuhi persyaratan dalam menyelesaikan Studi Kesarjanaan (S-1) di Departemen Teknik Kelautan, Fakultas Teknologi Kelautan, Institut Teknologi Sepuluh Nopember (ITS) Surabaya.

Tiada gading yang tak retak, tiada manusia yang sempurna. Penulis mohon maaf apabila terdapat kesalahan dalam penyusunan tugas akhir ini. Kritik dan saran yang baik senantiasa penulis nantikan sebagai petunjuk evaluasi diri. Akhir kata, semoga penelitian tugas akhir ini bermanfaat bagi perkembangan teknologi di bidang maritim, pembaca, dan penulis.

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Surabaya, Juli 2017

Moch Farid Azis

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# BAB I

# PENDAHULUAN

# BAB I
# PENDAHULUAN

## 1.1 Latar Belakang Masalah

Baja merupakan salah satu jenis logam yang paling banyak digunakan sebagai material utama dalam industri yang beroperasi di laut. Terdapat tiga jenis baja dipasaran menurut kandungan karbon dalam baja, yaitu baja karbon rendah, baja karbon sedang, dan baja karbon tinggi. Pada industri ini, baja karbon rendah adalah baja yang paling banyak digunakan. Dalam penyimpanan maupun penggunaannya, seperti material lain, baja mengalami pelapukan yang sering disebut korosi. Korosi diartikan sebagai kerusakan atau keausan dari material akibat terjadinya reaksi dengan lingkungan yang didukung oleh faktor-faktor tertentu (Supomo, 2003). Biaya tahunan dari seluruh bentuk korosi pada industri minyak dan gas di tahun 2011 diperkirakan mencapai $13,4 milyar (Bermont-Bouis, 2007).

Korosi yang terjadi pada logam tidak dapat dihindari, tetapi hanya dapat dicegah dan dikendalikan sehingga logam mempunyai masa pakai / guna lebih lama (Sidiq, 2013). Pemberian lapisan *coating* anti korosi merupakan salah satu cara untuk melindungi material dari proses korosi. Lapisan *coating* mengandalkan daya lekatnya untuk melindungi permukaan suatu material. Jika daya lekat *coating* meningkat, maka *life time* dari *coating* pun akan meningkat (Khorasanizadeh, 2010). Begitu pula sebaliknya, jika daya lekat *coating* turun, maka *life time* dari *coating* pun akan menurun. Daya lekat *coating* dipengaruhi oleh berbagai hal, salah satunya adalah ketebalan *coating*. Semakin tebal suatu *coating* tidak berarti hasilnya pasti semakin baik.

Keberhasilan dari proses *coating* sangat bergantung pada proses *surface preparation*, proses ini akan mempengaruhi kekuatan adhesi dari material (Hudson. 1982). Salah satu teknik dari *surface preparation* yang umum digunakan dalam dunia industri adalah *blasting*. Proses ini merupakan pembersihan permukaan dengan cara menembakan material abrasif ke suatu permukaan material dengan tekanan tinggi sehingga menimbulkan gesekan dan tumbukan. Permukaan material tersebut akan menjadi bersih dan kasar. Pemilihan dan penggunaan material abrasif yang tepat akan

menambah daya lekat cat. Oleh karena itu, pada penelitian ini akan dipelajari tentang analisa pengaruh material abrasif pada *blasting* terhadap kualitas *coating epoxy* pada material untuk aplikasi kelautan.

## 1.2 Perumusan Masalah

Dalam tugas akhir ini, permasalahan yang akan dibahas yaitu:

1. Bagaimana pengaruh material abrasif pada proses *blasting* terhadap kekasaran permukaan baja A36 dan A53?
2. Bagaimana pengaruh material abrasif pada proses *blasting* terhadap daya lekat *coating* pada baja A36 dan A53?
3. Material abrasif manakah yang paling cocok untuk proses *blasting* baja A36 dan A53?

## 1.3 Tujuan

Tujuan yang ingin dicapai dalam tugas akhir ini yaitu:

1. Mendapatkan pengaruh jenis material abrasif pada proses *blasting* terhadap kekasaran permukaan baja A36 dan A53.
2. Mendapatkan korelasi pengaruh material abrasif pada proses *blasting* terhadap daya lekat *coating* pada baja A36 dan A53.
3. Mendapatkan material abrasif mana yang paling cocok untuk baja A36 dan A53 sehingga dapat menghasilkan kualitas *coating* terbaik.

## 1.4 Manfaat

Manfaat yang diharapkan dari penelitian tugas akhir ini adalah:

1. Menjadi acuan dalam pemilihan material abrasif untuk proses *blasting* material, khususnya baja A36 dan A53.
2. Menjadi literatur yang saling melengkapi literatur hasil penelitian terdahulu khususnya mengenai material abrasif untuk proses *blasting*.

## 1.5 Batasan Masalah

Untuk memperjelas dan membatasi penelitian tugas akhir ini, maka perlu adanya batasan masalah atau asumsi-asumsi sebagai berikut:

1. Pelat baja yang digunakan adalah pelat baja karbon ASTM A36 dan A53.
2. Material abrasif yang digunakan untuk proses *blasting* adalah *steel grid*, garnet, dan silika.
3. Tekanan kompresor dianggap stabil.
4. Unsur pengotor dianggap tidak berpengaruh.
5. Cat yang digunakan adalah *epoxy*.
6. Ketebalan cat tiap spesimen memenuhi *product data* cat *epoxy* yang digunakan.
7. Analisa ekonomis tidak dilakukan

## 1.6 Sistematika Penulisan

1. Bab I Pendahuluan

   Bab ini menjelaskan beberapa hal yang melatarbelakangi sehingga penelitian ini penting untuk dilakukan dan layak untuk diajukan sebagai tugas akhir. Berisi latar belakang, rumusan masalah, dan tujuan yang ingin dicapai guna menjawab rumusan masalah serta manfaat dari adanya penelitian tugas akhir ini. Untuk memperjelas batasan masalah dan mempermudah penulisan, maka disertakan pula lingkup dan asumsi penelitian beserta sistematika penulisan tugas akhir ini.
2. Bab II Tinjauan Pustaka dan Dasar Teori

   Bab ini berisi referensi dan teori pendukung yang digunakan sebagai acuan dalam mengerjakan dan menyelesaikan tugas akhir ini. Referensi yang digunakan adalah jurnal lokal, jurnal internasional, literatur, *code*, dan buku yang sesuai dengan topik yang dibahas.
3. Bab III Metode Penelitian

   Bab ini menjelaskan alur pengerjaan tugas akhir yang digambarkan dengan diagram alir (*flow chart*). Diagram alir disusun secara sistematis dan dilengkapi data penelitian serta penjelasan detail tiap-tiap langkah pengerjaan.
4. Bab IV Analisis dan Pembahasan

   Bab ini menjelaskan data yang diperoleh dari pengujian dan pengolahan data serta analisa terhadap hasil yang diperoleh.

5. Bab V Penutup

   Bab ini berisi kesimpulan yang berupa uraian singkat dari keseluruhan hasil analisis. Uraian singkat ini menjawab rumusan masalah yang ada di bab I. Terdapat pula saran yang bermanfaat untuk penelitian lebih lanjut.

# BAB II

# TINJAUAN PUSTAKA

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# TINJAUAN PUSTAKA

## 2.1 Tinjauan Pustaka

Baja merupakan material utama dalam industri maritim dan industri minyak dan gas. Baja mempunyai sejumlah sifat yang membuatnya menjadi bahan bangunan yang sangat berharga. Beberapa sifat baja yang penting adalah: kekuatan, kelenturan, kealotan, kekerasannya. Baja berperan sebagai bahan dasar dalam pembuatan kapal dan berbagai bangunan lepas pantai. Perpaduan besi sebagai unsur dasar dengan beberapa elemen lainnya termasuk karbon dengan kadar berbeda menghasilkan baja dengan kualitas berbeda. Kandungan unsur karbon dalam baja berkisar antara 0.2% hingga 2.1% dari berat sesuai *grade*-nya. *Grade* baja karbon dibedakan menjadi tiga tingkatan, yaitu baja karbon rendah, baja karbon sedang, dan baja karbon tinggi. Masing-masing *grade* baja karbon memiliki kelebihan dan kekurangan pada sifatnya. Kandungan karbon yang besar dalam baja mengakibatkan meningkatnya kekerasan tetapi baja tersebut akan rapuh dan sulit dibentuk (Davis, 1998).

Material baja termasuk jenis logam yang rentan mengalami korosi. Terjadinya korosi dapat menyebabkan baja kehilangan kekuatannya sehingga tidak mampu berfungsi sebagaimana mestinya. Pengendalian korosi pada baja karbon merupakan kegiatan yang sangat penting secara teknis, ekonomis, lingkungan dan estetika (Umoren, 2008). Ketika suatu konstruksi baja mengalami korosi sehingga tidak dapat berfungsi secara teknis, maka baja tersebut harus diperbaiki atau bahkan diganti, yang berarti tentu timbul biaya baru. Pada konstruksi kecil mungkin bahaya dan biaya yang timbul akibat kegagalan baja tidak begitu besar, namun tentu akan sangat besar apabila konstruksinya besar, seperti kapal dan bangunan lepas pantai misalnya. Sehingga pemilihan, pencegahan, dan perawatan baja merupakan hal yang sangat penting.

Lingkungan laut merupakan lingkungan yang sangat korosif dan tidak bersahabat untuk logam jenis baja. Namun konstruksi bangunan di lingkungan laut membutuhkan hadirnya baja sebagai bahan konstruksi utamanya. Sehingga diperlukan suatu metode pencegahan korosi yang mampu mengakomodasi baja supaya baja dapat bertahan lama di lingkungan laut. Menurut Bundjali (2005), laju korosi dapat dicegah melalui beberapa

metode, di antaranya dengan proteksi katodik, *coating*, dan pemakaian bahan-bahan kimia. Metode-metode tersebut telah terbukti mampu mencegah laju korosi. Pada permukaan yang luas dan bersentuhan langsung dengan lingkungan yang korosif, pemberian lapisan *coating* menjadi metode utama pencegahan korosi. Proses *coating* ini merupakan hal yang sangat lumrah digunakan karena fleksibilitasnya dan kemampuannya menjadi *barrier* (dinding atau lapisan) pemisah antara baja dengan lingkungan yang korosif. *Coating* sebelum digunakan berwujud cair, sehingga dapat menyesuaikan bentuknya dengan permukaan material yang dilindungi. Setelah menempel beberapa waktu, *coating* akan mengeras dan efektif mencegah korosi. Aplikasi dari pelapisan cenderung mudah dan tanpa batas ukuran permukaan yang dapat dilapisi oleh cat (Hudson, 1982).

*Coating* tidak serta merta dapat andal dalam melindungi material dari korosi. Melainkan ada beberapa faktor yang mempengaruhi keandalan *coating*, di antaranya adalah bentuk permukaan material yang dilindungi, ketebalan lapisan *coating*, keadaan lingkungan ketika proses pemberian *coating* berlangsung, dan juga daya lekat *coating*. Nugroho (2016) dalam penelitiannya telah membuktikan bahwa ketahanan korosi suatu material juga dipengaruhi oleh kekuatan daya lekat cat, semakin besar daya lekat cat suatu material, maka ketahanan korosi material tersebut akan semakin baik. Berlaku pula sebaliknya, jika kekuatan daya lekat menurun, maka ketahanan korosi material pun akan menurun. Ketebalan *coating* sangat sulit untuk terbentuk presisi ukuran lapisan keringnya, sehingga dalam pengerjaan *coating* sangat lumrah didapati ketebalan lapisan yang berbeda-beda. Hal ini disebabkan oleh keadaan lingkungan dan proses *coating* yang masih dilakukan secara manual dengan tangan manusia. Lapisan *coating* yang terlalu tipis tidak bagus karena akan mudah ditembus air dan kehilangan daya lekat lalu terkelupas. Ketika bergesekan dengan benda keras juga lebih mudah terkelupas. Namun lapisan *coating* yang terlalu tebal juga tidaklah baik. Menurut Afandi (2015) semakin tebal suatu *coating* memiliki resiko kegagalan *coating* lebih besar seperti, berkurangnya fleksibilitas, terjadinya pengerutan, atau pengeringan yang tidak sempurna. Sehingga ketebalan lapisan *coating* harus sesuai dengan saran pada *product data sheet* yang dikeluarkan pabrik dan memenuhi standar / *rules* yang digunakan.

Keberhasilan dari proses *coating* sangat bergantung pada proses *surface preparation*, proses ini akan mempengaruhi kekuatan adhesi dari material (Hudson,

1982). Salah satu teknik dari *surface preparation* yang umum digunakan dalam dunia industri adalah *blasting*. Proses ini merupakan pembersihan permukaan dengan cara menembakkan material abrasif ke suatu permukaan material dengan tekanan tinggi sehingga menimbulkan gesekan / tumbukan. Permukaan material tersebut akan menjadi bersih dan kasar. Pemilihan dan penggunaan material abrasif yang tepat akan menambah daya lekat cat.

Terdapat banyak jenis material abrasif di pasaran dan digunakan untuk proses *surface preparation*, beberapa di antaranya adalah *Steel Grid, Volcanic Sand*, Garnet, Silika, dan *Alumunium oxide*. Proses *surface preparation* menggunakan material abrasif yang disemprotkan ke permukaan material yang akan diberi lapisan *coating* biasa disebut sebagai proses *blasting*. Proses *blasting* akan membersihkan permukaan material dari debu, minyak, air, dan zat pengotor lainnya, serta menghasilkan permukaan yang kasar namun bagus sebagai tempat melekatnya *coating*.

## 2.2 Baja

Baja merupakan logam paduan yang banyak digunakan untuk bidang rekayasa teknik. Kandungan unsur karbon dalam baja bermacam-macam sesuai dengan *grade*-nya. Baja karbon adalah logam paduan dengan komposisi utama besi (Fe) yang dipadu dengan karbon (C). Biasanya tercampur juga unsur-unsur bawaan lain seperti silikon 0,20% - 0,70%, Mn 0,50%-1,00%, P < 0,60% dan S < 0.06%. Sifat baja sangat tergantung pada kadar karbon, bila kadar karbon naik maka kekuatan dan kekerasan juga akan naik (Davis, 1998). Karena itu baja karbon dikelompokkan berdasarkan kadar karbonnya (Wiryosumatro, 2000). Menurut Saito (2000), baja karbon menurut komposisi kimianya dibedakan menjadi 3, yaitu sebagai berikut:

1. Baja Karbon Rendah

   Baja karbon rendah dengan kadar karbon 0,05-0,3% (*low carbon steel*). Sifatnya mudah ditempa dan mudah dimesin. Biasanya digunakan untuk bodi mobil, bus dan lain-lain
2. Baja Karbon Sedang

   Baja karbon menengah dengan kadar karbon 0,3-0,5% (*medium carbon steel*). Kekuatannya lebih tinggi daripada baja karbon rendah. Sifatnya sulit

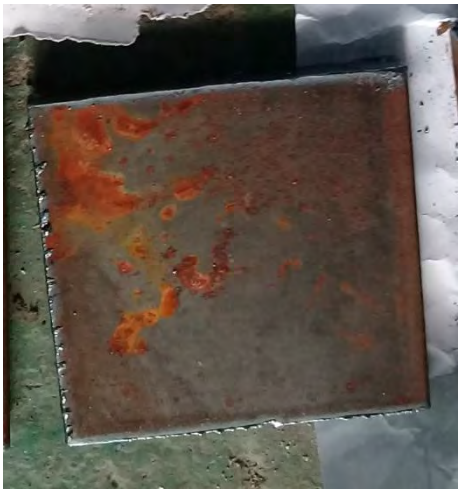
dibengkokkan, dilas, dan dipotong. Penggunaannya untuk konstruksi bangunan, bahan pada komponen mesin, golok, pisau dan lain-lain.

3. Baja Karbon Tinggi

   Baja karbon tinggi dengan kadar karbon 0,5-1,5% (*hight carbon steel*). Sifatnya sulit dibengkokkan, dilas dan dipotong. Penggunaannya seperti pada baja kawat, kabel tarik dan angkat, kikir, pahat, dan gergaji.

## 2.3 Baja ASTM A36

Baja ASTM A36 adalah baja yang paling banyak digunakan dalam industri maritim. Baja ini termasuk baja karbon rendah karena mengandung karbon antara 0.1% - 0,3%. Baja ini memiliki sifat las yang baik. Biasanya digunakan untuk bodi kapal dan *main frame* bangunan lepas pantai. Berikut ini adalah gambar potongan baja ASTM A36 yang digunakan dalam penelitian tugas akhir ini. Material baja pada gambar 2.1 di bawah ini permukaannya telah mengalami korosi.



**Gambar 2.1.** Potongan baja ASTM A36

## 2.4 Baja ASTM A53

Baja ASTM A53 adalah baja yang cukup banyak digunakan dalam industri maritim. Baja ini lebih kuat dibanding baja ASTM A36 karena kadar karbonnya lebih tinggi, namun baja ini lebih getas. Kadar karbon baja ASTM A53 berkisar antara 0,3-0,5%. Berikut ini adalah gambar potongan baja ASTM A53 yang digunakan dalam penelitian tugas akhir ini. Material baja pada gambar 2.2 di bawah ini berwarna demikian karena

permukaannya mengalami korosi, sama seperti material baja pada gambar 2.1, sehingga harus dilakukan proses *blasting* sebelum dilakukan proses *coating*.

**Gambar 2.2** Potongan baja ASTM A53

## 2.5 Korosi

Pada umumnya korosi yang didefinisikan sebagai kerusakan atau degradasi material yang disebabkan oleh reaksi antara material dengan lingkungannya. Material yang terkorosi memiliki sifat dan kualitas yang lebih rendah dari material yang sama yang tidak mengalami korosi. Apabila korosi terjadi terus menerus, maka material lama kelamaan akan berubah seluruhnya menjadi produk korosi.

Komponen utama dalam korosi ada dua yaitu material dan lingkungan. Material dapat berupa logam seperti besi dan baja maupun non-logam seperti keramik, karet, plastik. Lingkungan dapat berupa kelembaban udara, asam atau basa, gas, temperatur, dan lain-lain. Korosi dapat berlangsung secara cepat atau lambat bergantung pada tingkat keaktifan reaksi material tersebut dengan lingkungannya. Reaksi yang terjadi dapat berupa reaksi kimia, elektrokimia, atau secara mekanik.

Korosi secara umum terbagi menjadi beberapa jenis berdasarkan bentuk dan mekanisme terjadinya. Berikut adalah macam-macam korosi yang sering terdapat dalam industri:

1. Korosi merata / seragam (*uniform corrosion*)
2. Korosi galvanis (*galvanic corrosion*)

3. Korosi celah (*crevice corrosion*)
4. Korosi sumur (*pitting corrosion*)
5. Korosi butiran (*intergaranular corrosion*)
6. Korosi selektif (*selective corrosion*)
7. Korosi erosi (*erosion corrosion*)
8. Korosi tegangan (*stress corrosion*)
9. Korosi lelah (*fatigue corrosion*)
10. Korosi biologi (*biological corrosion*)

### 2.5.1 Korosi Merata / Seragam (*Uniform Corrosion*)

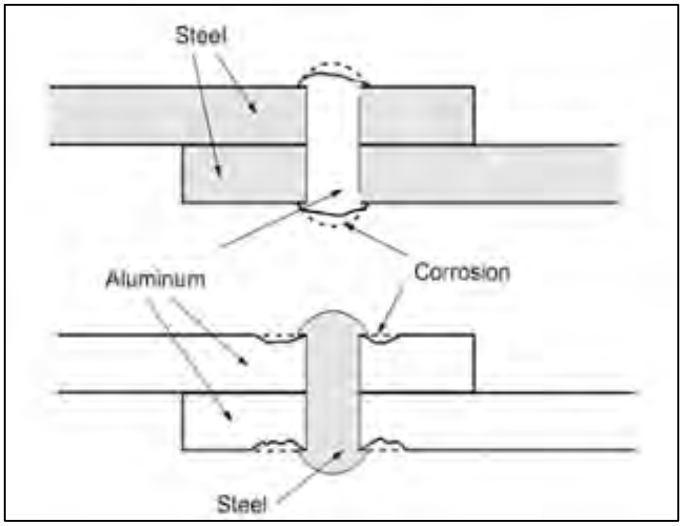
Korosi jenis ini terjadi secara menyeluruh, seluruh permukaan logam yang terekspose dengan lingkungan terkorosi secara merata. Jenis korosi ini mengakibatkan rusaknya konstruksi secara total. Pada *uniform corrosion* terjadi distribusi seragam dari reaktan katodik atas seluruh permukaan logam yang terekspose. Pada lingkungan asam (pH < 7), terjadi reduksi ion hidrogen dan pada lingkungan basa (pH > 7) atau netral (pH = 7), terjadi reduksi oksigen. Kedua berlangsung secara seragam dan tidak ada lokasi preferensial atau lokasi untuk reaksi katodik atau anodik. Katoda dan anoda terletak secara acak dan bergantian dengan waktu. Hasil akhirnya adalah hilangnya lapisan permukaan awal dengan ukuran yang kurang lebih sama / seragam. Terdapat dua metode untuk pencegahannya, yaitu dengan melakukan pelapisan dengan cat atau dengan material yang lebih anodik dan melakukan inhibitas dan proteksi katodik (*cathodik protection*). Berikut adalah gambar *bollord* yang telah mengalami *uniform corrosion*.

**Gambar 2.3** *Uniform corrosion* pada *bollard*
(sumber: *https://www.nace.org*)

### 2.5.2 Korosi Galvanis (*Galvanic Corrosion*)

*Galvanic* atau *bimetalic corrosion* adalah jenis korosi yang terjadi ketika dua macam logam yang berbeda berkontak secara langsung dalam media korosif. Korosi ini terjadi karena proses elektro kimiawi dua macam metal yang berbeda potensial yang dihubungkan langsung di dalam elektrolit yang sama. Di mana elektron mengalir dari metal anodik menuju metal katodik, akibatnya metal anodic berubah menjadi ion – ion positif karena kehilangan elektron. Ion-ion positif metal bereaksi dengan ion negatif yang berada di dalam elektrolit menjadi garam metal. Karena peristiwa tersebut, permukaan anoda kehilangan metal sehingga terbentuklah sumur - sumur karat (*Surface Attack*) atau serangan karat permukaan. Berikut adalah gambar pipa air yang terkorosi secara galvanis.

**Gambar 2.4** *Galvanic corrosion* pada pipa air dari logam
(Sumber: *https://www.nachi.org/*)




**Gambar 2.5.** Mekanisme korosi galvanis
(Sumber: *http://m10mechanicalengineering.blogspot.co.id/*)

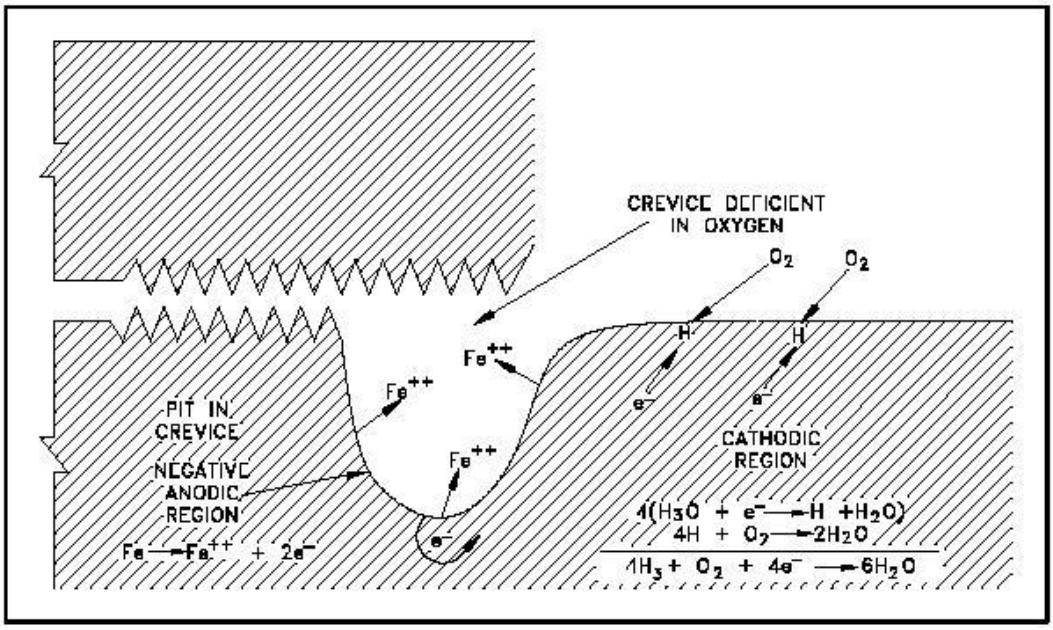
Berikut adalah beberapa metode yang dilakukan dalam pengendalian korosi galvanis:

1. Menekan terjadinya reaksi kimia atau elektrokimianya seperti reaksi anoda dan katoda.
2. Mengisolasi logam dari lingkungannya.
3. Mengurangi ion hydrogen di dalam lingkungan yang di kenal dengan mineralisasi.
4. Mengurangi oksigen yang larut dalam air.
5. Mencegah kontak dari dua material yang tidak sejenis.
6. Memilih logam-logam yang memiliki unsure-unsur yang berdekatan.
7. Mencegah celah atau menutup celah.
8. Mengadakan proteksi katodik, dengan menempelkan anoda umpan.

### 2.5.3 Korosi Celah (*Crevice Corrosion*)

Korosi celah mengacu pada serangan lokal pada permukaan logam yang mana celah antar permukaan sangat berdekatan dan bahkan bergabung menjadi satu celah yang lebih besar. Celah dapat terbentuk antara dua logam atau logam dengan non-logam. *Crevice Corrosion* dimulai dengan adanya perbedaan konsentrasi beberapa kandungan kimia, biasanya oksigen, yang membentuk konsentrasi sel elektrokimia (perbedaan sel aerasi dalam kasus oksigen). Di luar dari celah (katoda), kandungan oksigen dan pH lebih tinggi - tetapi klorida lebih rendah. Gambar korosi celah dan mekanisme terjadinya dapat dilihat pada gambar 2.6 dan 2.7 berikut:

**Gambar 2.6.** Korosi celah pada pipa logam.
(Sumber: *http://www.offhoreenergy.dk/*)




**Gambar 2.7** Mekanisme terjadinya korosi celah.
(Sumber: *http://www.tpub.com/*)

Berikut adalah beberapa cara yang dapat dilakukan untuk menghindari terjadinya korosi celah:

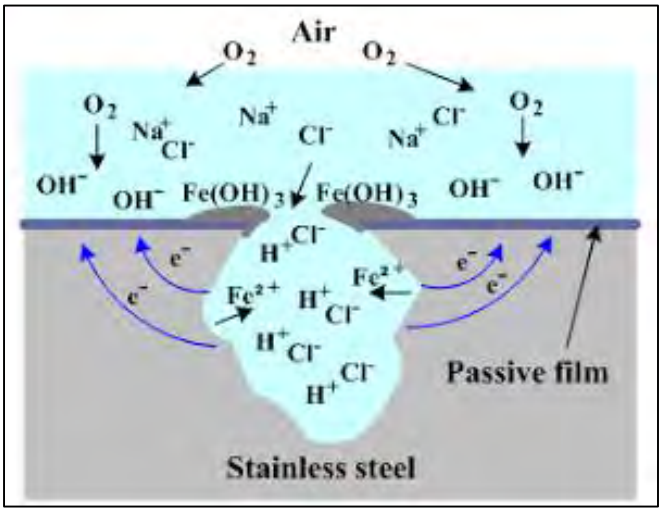
1. Menghindari pemakaian sambungan paku *keeling* atau baut, gunakan sambungan las.
2. Menggunakan gasket *non absorbing*.
3. Mengusahakan menghindari daerah dengan aliran udara.

### 2.5.4 Korosi Sumur (*Pitting Corrosion*)

Korosi sumuran adalah korosi lokal dari permukaan logam yang berupa titik-titik banyak dengan kedalaman yang bervariasi. Disebut korosi sumur karena korosinya tidak melebar kesamping, melainkan semakin kedalam seperti sumur. Korosi sumuran (*pitting corrosion*) adalah salah satu jenis korosi yang paling merusak. Contoh keadaan logam yang telah mengalami *pitting corrosion* dapat dilihat pada gambar 2.8 berikut:

**Gambar 2.8.** Wastafel yang telah mengalami *pitting corrosion*.
(Sumber: *http://m10mechanicalengineering.blogspot.co.id/*)

Pada material yang awalnya bebas cacat, korosi sumuran disebabkan oleh lingkungan kimia yang mungkin berisi spesies unsur kimia agresif seperti klorida. Klorida sangat merusak lapisan pasif (oksida) sehingga *pitting* dapat terjadi pada dudukan oksida. Lingkungan juga dapat mengatur perbedaan sel aerasi (tetesan air pada permukaan baja, misalnya) dan *pitting* dapat dimulai di lokasi anodik (pusat tetesan air). Mekanisme *pitting corrosion* dapat dilihat pada gambar 2.9 berikut:




**Gambar 2.9.** Mekanisme terjadinya *pitting corrosion*
(Sumber: *http://www.substech.com/*)

Berikut adalah beberapa cara yang dapat dilakukan untuk menghindari korosi sumuran :

1. Hindari permukaan logam dari goresan.
2. Perhalus permukaan logam.
3. Menghindari komposisi material dari berbagai jenis logam.

### 2.5.5 Korosi Butiran (*Intergranular Corrosion*)

*Intergranular corrosion* terkadang juga disebut "*intercrystalline corrosion*". Dengan adanya tegangan tarik, retak dapat terjadi sepanjang batas butir, sehingga jenis korosi ini sering disebut juga sebagai "intergranular retak korosi tegangan" atau "*intergranular stress corrosion cracking* (IGSCC)". Penampilan pemukaan *intergranular corrosion* dapat dilihat pada gambar 2.10.

Berikut adalah beberapa cara yang dapat dilakukan untuk mencegah adanya *intergranular corrosion*:

1. Turunkan kadar karbon dibawah 0,03%.
2. Tambahkan paduan yang dapat mengikat karbon.
3. Pendinginan cepat dari temperatur tinggi.
4. Pelarutan karbida melalui pemanasan.
5. Hindari adanya pengelasan.

**Gambar 2.10.** *Intergranular corrosion* pada bagian dalam pipa logam.
(Sumber: *http://cdcorrosion.com/*)

### 2.5.6 Korosi Selektif (*Selective Corrosion*)

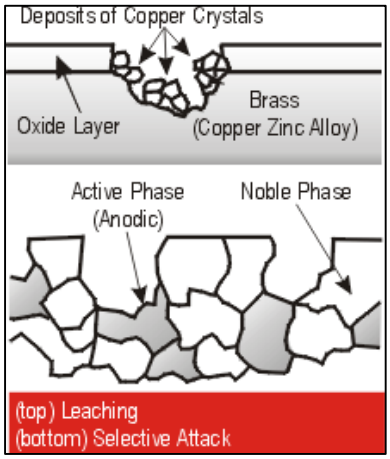
Korosi Selektif atau s*elective corrosion* atau *selective leaching* adalah suatu bentuk korosi yang terjadi karena pelarutan komponen tertentu dari paduan logam (*alloy*-nya). Pelarutan ini terjadi pada salah satu unsur pemadu atau komponen dari paduan logam yang lebih aktif yang menyebabkan sebagian besar dari pemadu tersebut hilang dari paduannya. Material yang tertinggal telah kehilangan sebagian besar kekuatan fisiknya (karena berpori-pori). *Selective corrosion* bisa terjadi dari sepasang panduan logam satu fasa dan juga dua fasa. Dalam paduan dua fasa, fasa yang kurang mulia akan meluruh terlebih dahulu.

Bentuk korosi ini juga disebut pemisahan atau dealloying. Pemadu yang biasaanya terlarut dari paduan logamnya adalah seng (Zn), alumunium (Al), kobalt (Co), nikel (Ni), dan *chrome* (Cr). Beberapa contoh korosi selektif dari paduan logam dengan logam Cu dapat dilihat pada tabel berikut ini :

**Tabel 2.1** Paduan logam dan non-logam yang menyebabkan *selective corrosion*

| Bentuk Korosi Selektif | Paduan | Logam Yng Terlarut |
|---|---|---|
| Dezincfikasi | Cu – Zn | Zn |
| Dealuminasi | Cu – Al | Al |
| Demanganisasi | Cu – Mn | Mn |
| Denikelisasi | Cu – Ni | Ni |
| Desilikonisasi | Cu – Si | Si |
| Decuprifikasi | Cu - Ag | Cu |

Sumber: *http://angelfire.com/*




**Gambar 2.11**. Mekanisme *selective corrosion*
(Sumber: *http://www.azom.com/*)

### 2.5.7 Korosi Erosi (*Erosion Corrosion*)

Korosi erosi adalah percepatan atau penambahan keburukan sifat material karena gerakan relatif antara fluida korosif dan permukaan metal. Faktor yang mempengaruhi diantaranya adalah: luas permukaan, kecepatan, turbulensi, dan efek galvanis. Bertambahnya kecepatan secara umum akan mengakibatkan bertambahnya pengikisan terutama jika diselubungi aliran yang berkecepatan kuat. Turbulensi mengakibatkan gerakan cairan lebih besar pada permukaan logam dibanding laminar dan terjadi persentuhan yang lebih kuat antara logam dengan sekitarnya. Berikut adalah gambar bagian dalam mesin pompa yang mengalami korosi erosi:

**Gambar 2.12** Korosi erosi pada bagian dalam mesin pompa.
(Sumber: *http://www.ricksfreeautorepairadvice.com/*)

Beberapa cara untuk mengatasi korosi di antaranya adalah:

1. Menggunakan material dengan ketahanan korosi yang baik
2. Penambahan diameter (jika logam yang dialiri berupa pipa) membantu dari segi mekanika dalam hal pengurangan kecepatan dan membuat agar aliran yang terjadi adalah aliran laminar
3. *Deareation* dan penambahan inhibitor
4. *Coating* dan *cathodic protection*

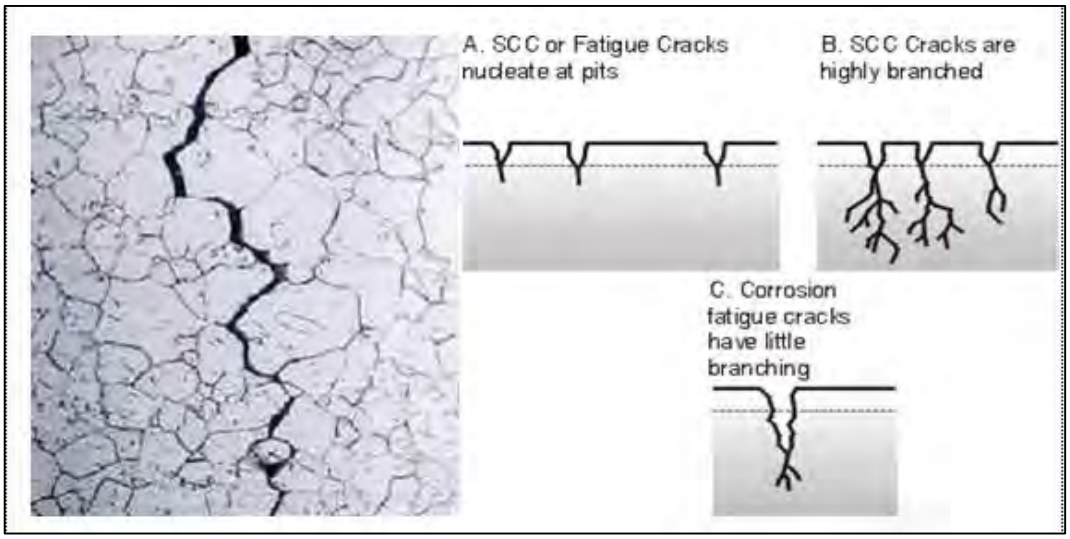
### 2.5.8 Korosi Retak Tegangan (*Stress Corrosion Creacking*)

Korosi retak tegangan atau *stress corrosion cracking* (SCC) adalah proses retak yang memerlukan aksi secara bersamaan dari bahan perusak (karat) dan

berkelanjutan dengan tegangan tarik. *Stress corrosion cracking* (SCC) terjadi akibat adanya hubungan dari 3 faktor komponen, yaitu (1) Bahan rentan terhadap korosi, (2) adanya larutan elektrolit (lingkungan) dan (3) adanya tegangan. Sebagai contoh, tembaga dan paduan rentan terhadap senyawa amonia, baja ringan rentan terhadap larutan alkali dan baja tahan karat rentan terhadap klorida. Mekanisme terjadinya *Stress corrosion cracking* (SCC) dapat dilihat pada gambar 2.13.

Berikut adalah beberapa cara yang dapat dilakukan untuk menghindari *Stress corrosion cracking* (SCC):

1. Menurunkan besarnya tegangan
2. Menurunkan tegangan sisa termal
3. Mengurangi beban luar atau perbesar area potongan
4. Menggunakan inhibitor.




**Gambar 2.13.** Mekanisme terjadinya *stress corrosion cracking* (SCC).
(Sumber: *http://wiwinwibowo.wordpress.com/*)

### 2.5.9 Korosi Lelah (*Fatigue Corrosion*)

Setiap material memiliki masa kerja yang berbeda-beda dan dapat mengelami kelelahan (*fatigue*) setelah beberapa lama digunakan. Korosi lelah ini terjadi karena adanya beban yang terjadi secara berulang dan terus menerus hingga

melebihi ambang batas kemampuan material. Setelah melebihi ambang batas, material akan mengalami *fatigue* dan gagal.

### 2.5.10 Korosi Biologi (*Biological Corrosion*)

Korosi biologi atau *biological corrosion* disebabkan oleh adanya kumpulan mikroorganisme seperti bakteri, jamur, dan alga yang terdapat pada cairan yang terkontaminasi. Korosi biologi terjadi pada cuaca yang panas dan lembab. Mikroorganisme atau jamur menghasilkan interaksi elektrokimia yang berhubungan langsung dengan kelembaban. Keadaan adanya senyawa biologi dan lingkungan yang sangat mendukung menyebabkan terjadinya korosi biologi.

## 2.6 Pencegahan Korosi

Korosi dapat menimbulkan kerugian yang sangat besar. Diperlukan biaya tinggi untuk merenovasi suatu material yang telah terkorosi. Korosi juga dapat menyebabkan terjadinya hubungan pendek (*konsleting*) arus listrik. Mengingat banyaknya kerugian yang diakibatkan oleh korosi, maka perlu dilakukan suatu cara untuk mencegah berlangsungnya korosi. Berikut beberapa cara yang dilakukan untuk mencegah korosi:

a. Pengecatan (*coating*)

   Pengecatan atau *coating* merupakan metode yang paling banyak digunakan di lingkungan laut. Cat menjadi *barrier* atau penyekat antara logam konstruksi dengan lingkungannya. Bisa dikatakan seluruh konstruksi di lingkungan laut pasti dilapisi *coating*, terutama yang bersentuhan dengan air laut seperti lambung kapal misalnya.

b. *Tin plating* (pelapisan dengan timah)

   Kaleng kemasan biasanya terbuat dari besi yang di lapisi dengan timah. Pelapisan dilakukan dengan cara elektrolisis, yang disebut *electroplating*. Timah tergolong logam yang tahan karat. Besi yang dilapisi timah tidak mengalami korosi karena tidak ada kontak dengan oksigen (udara) dan air. Akan tetapi, lapisan timah hanya melindungi besi selama lapisan itu utuh (tanpa cacat). Apabila lapisan timah ada yang rusak, misalnya tergores, maka timah justru mempercepat laju korosi besi. Hal ini terjadi karena potensial reduksi besi lebih negatif daripada timah.

c. Galvanisasi (pelapisan dengan *zink*)

*Zink* memiliki mekanisme pelindungan yang mirip dengan timah, namun *zink* dapat melindungi besi dari korosi sekalipun lapisannya tidak utuh. Hal itu terjadi karena suatu mekanisme yang disebut perlindungan katode. Oleh karena potensial reduksi besi lebih positif di bandingkan *zink*, maka besi yang kontak dengan *zink* akan membentuk sel elektrokimia dengan besi sebagai katode. Sehinggga besi terlindung dari korosi. Biasanya diaplikasikan pada pipa besi, tiang telpon, dan badan mobil.

d. *Cromium plating* (pelapisan dengan kromium)

Mekanisme pelindungannya sama seperti *zink*. Perbedaan utama antara *chromium plating* dengan *zink* adalah lapisan pelindung dengan *chromium plating* terlihat mengkilap. Biasanya diaplikasikan pada *bumper* mobil dan *knalpot* sepeda motor.

e. Membalut dengan plastik

Mekanisme yang terjadi sama seperti *coating*, yaitu menciptakan *barrier* atau penghalang antara logam dengan lingkungannya. Namun kekuatan plastik tidak sekuat *coating*.

f. Melumuri material dengan oli

Oli mencegah kontak besi dengan air. Metode ini biasanya diterapkan untuk berbagai perkakas dan mesin.

g. *Sacrifical protection* (pengorbanan anode)

Magnesium adalah logam yang jauh lebih aktif (lebih mudah berkarat) daripada besi, sehingga ketika terjadi mekanisme korosi, magnesium akan berkarat tetapi besi tidak. Biasanya diterapkan pada pipa baja dan badan kapal. Secara periodik, magnesium akan habis dan harus diganti.

## 2.7 *Coating*

*Coating* merupakan suatu penghalang (*barrier*) antara baja dengan lingkungan sehingga tidak ada interaksi langsung di antara keduanya. *Coating* juga tidak terbatas pada logam tertentu saja. Pelapisan *coating* dibedakan menjadi 2 jenis, yaitu *liquid*

*coating* dan *concrete coating*. *Liquid coating* adalah pelapisan material dengan cara pengecatan permukaan. Sedangkan *concrete coating* adalah pelapisan material dengan cara melapisi permukaan dengan beton. Berbeda jenis cat *coating*, berbeda pula ketebalan yang disarankan. Berikut potongan tabel STG *Guideline* No. 2215 dalam buku regulasi BKI (2004) yang menyarankan tebal minimal lapisan kering *coating epoxy* adalah 250 µm. Dalam pemberian *coating*, tebal lapisan *coating* tidak hanya mengacu pada standard yang digunaka, melainkan harus mengacu pula pada *product data sheet* dari pabrik yang memproduksi *coating* tersebut.

**Tabel 2.1** Ketebalan *coating* berdasarkan STG *Guideline* No.2215.



**Table 4.3 Examples for suitable coating systems, based on STG-Guideline-No. 2215**

| Areas | Type of binder | Standard preparation grade (before coating) | Minimum film thickness [µm] | | | Remarks |
|---|---|---|---|---|---|---|
| | | | Undercoat | Topcoat | Total dry film thickness | |
| Underwater shell plating / see water ballast tanks | Epoxy (resin) (EP) | Sa2½ | 1 x 500 | | 500 | solvent-free, ice-going ships |
| | | PSa2½ | 1 x 125 | 1 x 125 | 250 | |
| | Epoxy (resin) tar combination (TE) | PSa2½ | 1 -2 x 125 | 1 x 125 | 250 -375 | |
| | | | 1 x 300 | | 300 | solvent-free |
| | Polyurethane (PUR) | | 2 x 100 | 1 X 100 | 300 | |
| | Polyurethane tar combination (PUR-T) | | 1 x 125 | 1 x 125 | 250 | |
| | Polyvinylchloride (PVC) | | 3 x 100 | | 300 | |
| | Polyvinylchloride tar combination (PVC-T) | | 2 x 100 | 1 X 100 | 300 | |
| | Chlorinated rubber (RUC) | | 2 x 90 | 1 X 90 | 270 | |
| | Tar (T) | PSa2½ / St3 | 1 x 125 | 1 x 125 | 250 | |

Sumber: BKI, 2004

## 2.8 *Epoxy*

*Epoxy* adalah bahan kimia yang merupakan salah satu jenis *coating* anti korosi. *Epoxy* adalah resin yang diperoleh dari proses polimerisasi epoksida. *Epoxy* resin bereaksi dengan beberapa bahan kimia lain seperti amina polifungsi, asam serta fenol dan alkohol yang umumnya dikenal sebagai bahan pengeras atau *hardener*. Setelah dicampur, *epoxy* dan *hardener* akan berubah dari cair ke padat dan menjadi sangat kuat, tahan suhu tinggi tertentu dan memiliki ketahanan kimia yang tinggi. *Epoxy* resin memiliki sifat adhesi yang kuat, sehingga sangat baik untuk menjadi lapisan *coating* pelindung logam, kayu, baja, beton, dan beberapa material lain dari korosi.

Saat ini epoxy tidak hanya digunakan sebagai pencegah korosi pada logam konstruksi di lingkungan laut. Epoxy telah banyak digunakan di darat, di antaranya digunakan sebagai pelindung pada cerobong asap, lantai, tembok, dan *body* kendaraan. Epoxy juga telah diperhatikan dari segi estetikanya, sehingga tidak jarang ditemui epoxy dengan berbagai warna yang menarik. Namun proses pemberian lapisan epoxy tetap harus memperhatikan permukaan yang akan dilapisi, karena kunci dari kekuatan / ketahanan epoxy ini salah satunya ada pada profil kekasaran permukaan.

## 2.9 Material Abrasif

Abrasif berasal dari kata abrasi yang berarti suatu proses pengikisan permukaan. Material abrasif adalah material yang menurut fungsinya digunakan untuk mengabrasi permukaan material lain, sehingga tercapai tingkat kekasaran tertentu. Sedangkan menurut Anusavice (2004), abrasi adalah suatu proses untuk pelepasan suatu bahan yang dikenakan pada permukaan suatu bahan oleh bahan yang lain dengan penggosokan, pencungkilan, pemahatan, pengasahan atau dengan cara mekanis lainnya secara berulang ulang oleh suatu gesekan. Material abrasif menurut jenisnya dibedakan menjadi dua, yaitu material metal dan non-metal.

Macam-macam material abrasive:

a. Metal

   Material abrasif jenis metal ini di antaranya adalah *steel grid, steel shot,* dan *wire cut carbon*.

b. Non Metal

Material abrasif jenis non metal di antaranya adalah pasir silika, garnet, *aluminium oxide*, karbida, *glass bead*, *walnut sheel*, dan *volcanic sand*.

## 2.10 *Sand Blasting*

*Sandblasting* adalah suatu proses pembersihan dengan cara menembakan partikel (pasir) ke suatu permukaan material sehingga menimbulkan gesekan atau tumbukan. Permukaan material tersebut akan menjadi bersih dan kasar. Tingkat kekasaranya dapat disesuaikan dengan ukuran pasir serta tekananya. *Sandblasting* banyak digunakan untuk berbagai macam fungsi, yaitu:

c. Digunakan untuk menghilangkan karat, debu, cat, dan pengotor lainya.
d. Digunakan untuk membentuk kekasaran permukaan pada persiapan untuk proses pelapisan.

Di dalam persiapan permukaan dengan metode ini, harus dilakukan dengan hati – hati dan oleh tenaga yang terampil dan berpengalaman. Sebab apabila dilakukan oleh orang awam besar kemungkinan orang tersebut justru dapat memperparah keadaan karena material yang digunakan menjadi rusak dan bahkan bisa terjadi kecelakaan kerja yang fatal. *Sandblasting* dibagi menjadi 2 jenis bedasarkan pengunaannya, yaitu:

1. *Dry Sandlasting*

   Biasa digunakan untuk benda yang berbahan metal / besi yang tidak beresiko menghasilkan percikan api pada saat penyemprotan , seperti pada tiang pancang, bodi pada rangka mobil, bodi kapal laut, dan lain sebagainya.

2. *Wet Sandblasting*

   Biasa digunakan untuk benda yang berbahan metal / besi yang dapat beresiko terbakar atau terletak di daerah yang beresiko tinggi dalam hal kebakaran, seperti tangki bahan bakar atau kilang minyak (*offshore*). Wet sandblasting ini dicampurkan dengan bahan kimia khusus antikarat yang dapat meminimalisir percikan api ketika proses *sandblasting* dilakukan.

Berikut adalah parameter yang mempengaruhi proses *sandblasting*:

1. Ukuran butir ( *mesh size* )

   Ukuran butir berkaitan dengan bentuk profil permukaan yang terbentuk. Pada butiran yang kecil, bentuk profil permukaan yang dihasilkan cenderung lebih halus dibandingkan dengan ukuran butir yang lebih besar.

2. Sudut penyemprotan

   Sudut penyemprotan adalah besarnya sudut yang digunakan dalam penyemprotan antara *nozzle* dengan benda kerja yang disemprotkan sudut yang biasa digunakan dalam penyemprotan antara $60^{o}$ – $120^{o}$. Sudut $90^{o}$ terhadap permukaan menghasilkan tumbukan yang paling besar.

3. Tekanan penyemprotan

   Tekanan penyemprotan mempengaruhi daya dari abrasifnya. Semakin besar tekanan yang digunakan, maka daya abrasifnya juga semakin besar.

4. Jarak penyemprotan

   Jarak penyemprotan adalah jarak antara *nozzle* dengan benda kerja yang disemprot. Jarak penyemprotan bisa diatur sesuai dengan hasil yang diinginkan.

5. Waktu penyemprotan

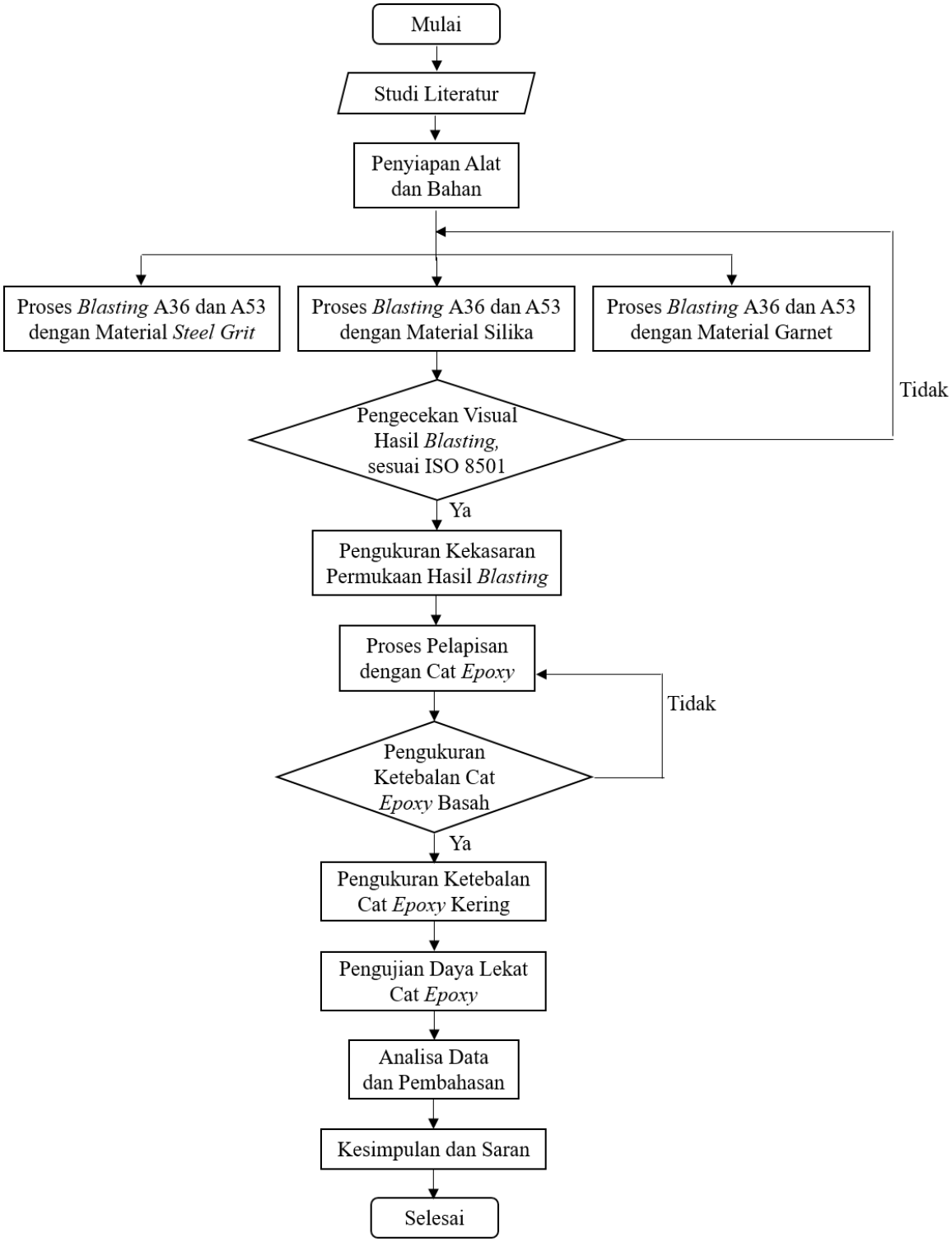
   Waktu penyemprotan permukaan dapat mempengaruhi kekasaran permukaan benda kerja. Semakin lama penyemprotan, maka permukaan yang dihasilkan semakin kasar. Rentang waktu yang digunakan ketika proses penyemprotan biasanya didasarkan pengalaman operator. Dalam beberapa kasus waktu yang diperlukan selama 40 – 80 detik untuk setiap luasan penyemprotan.

# BAB III

# METODOLOGI PENELITIAN

# BAB III
# METODOLOGI PENELITIAN

## 3.1 Diagram Alir Penelitian




**Gambar 3.1** Diagram Alir Penelitian

## 3.2 Prosedur Penelitian

Berdasarkan diagram alir penelitian di atas, prosedur penelitian dan langkah-langkah penelitian dalam mencapai tujuan tugas akhir ini dijelaskan sebagai berikut:

### 3.2.1 Studi Literatur

Studi dan pengumpulan literatur sebagai bahan-bahan referensi dan sumber teori-teori yang diperlukan dalam penyelesaian tugas akhir ini.

### 3.2.2 Penyiapan Alat dan Bahan

Berikut adalah daftar peralatan dan bahan yang digunakan dalam penelitian tugas akhir ini:

Alat-alat Penelitian:

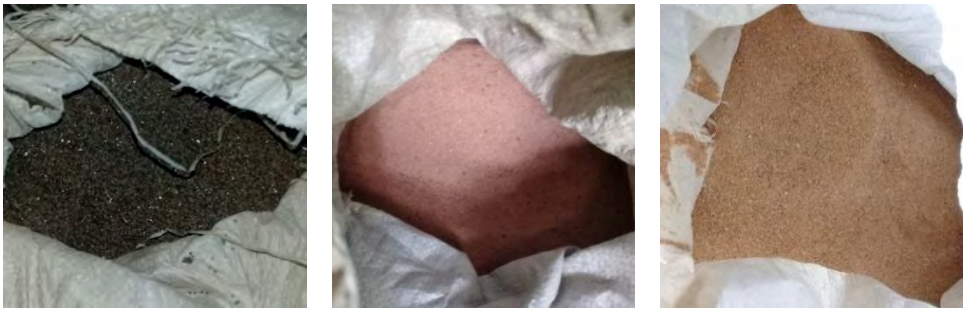
a. Peralatan *dry abrasive blast cleaning*
b. *Roughness meter*
c. Alat cat (*air spray gun*)
d. Alat ukur WFT (*wet film thickness gauge*)
e. Alat ukur DFT (*coating thickness gauge*)
f. Peralatan *pull-off test*
g. *Print* gambar acuan uji visual standar ISO 8501-01

Bahan Penelitian:

a. Pelat baja ASTM A36 (100 mm x 100 mm x 8 mm)
b. Pelat baja ASTM A53 (100 mm x 100 mm x 16 mm)
c. Cat *epoxy*
d. Material abrasif jenis *steel grit,* garnet, dan silika

### 3.2.3 Proses *Blasting*

Melakukan proses *blasting* dengan material abrasif jenis *steel grit,* garnet, dan silika. Dua spesimen pertama di-*blasting* dengan material abrasif jenis *steel grid*. Dua spesimen kedua di-*blasting* dengan material abrasif jenis garnet. Dua spesimen ketiga atau terakhir di-*blasting* dengan material abrasif jenis silika. *Steel grid* memiliki nilai kekasaran sekitar 4 hingga 4,5 skala mohs. Garnet memiliki nilai kekasaran 8,5 skala mohs. Sedangkan silika memiliki nilai kekasaran 7 skala mohs.



(a) (b) (c)

**Gambar 3.1** (a) *Steel Grid*, (b) Garnet, (c) Silika

Proses ini dilakukan untuk membersihkan dan memperkasar permukaan baja. Setelah proses *blasting* dilakukan, akan terlihat warna baja yang sebenarnya yang bebas dari korosi, debu, maupun zat pengotor lainnya. Tingkat kebersihan yang ingin dicapai dalam proses *blasting* ini adalah Sa 3 ISO 8501-01 atau jika dalam standard SSPC-VIS 1 adalah SP 5. Peralatan yang digunakan adalah seperangkat *Dry Abrasive Blast Cleaning*. Gambar ilustrasi seperangkat *Dry Abrasive Blast Cleaning* dapat dilihat pada gambar 3.2 berikut:

**Gambar 3.2** Seperangkat peralatan *Dry Abrasive Blast Cleaning.*
(Sumber: *http://www.paintingequipmentindonesia.com*)

Berikut ini adalah detail langkah-langkah proses *blasting*:

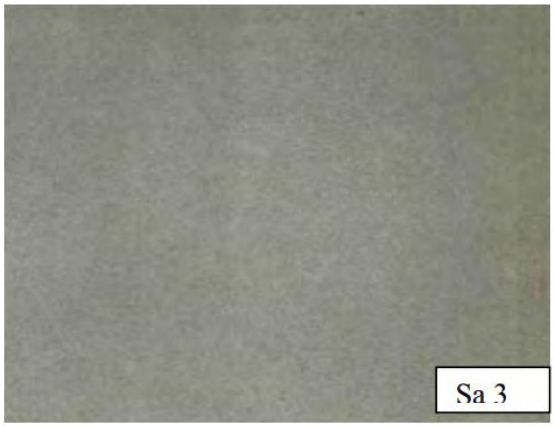
1. Membersihkan plat yang akan di Sandblasting dengan cara manual, yaitu dengan membersihkan permukaan dengan amplas atu cairan untuk menghilangkan kotoran

2. Mempersiapkan alat dan bahan seperti kompresor, bak pasir, selang, *nozzle*, tempat kerja, dan material yang akan di-*blasting* permukaannya.
3. Pasir yang telah disiapkan dimasukkan ke dalam bak pasir, pasir harus dalam keadaan kering. Kapasitas pasir yang dimasukkan seharusnya adalah 80% dari volume bak pasir, hal ini bertujuan untuk mengurangi resiko pasir yang terbuang akibat tumpah. Untuk pengisian kembali dapat dilakukan setelah volume berkurang hingga 40%.
4. Setelah pasir dimasukkan ke dalam bak pasir maka katup bak pasir dibuka. Katup inilah yang menjadi jalur keluar bak pasir sebelum dan selama di beri tekanan udara.
5. Menyalakan mesin kompresor. Mesin yang digunakan di kebanyakan galangan di Indonesia adalah mesin kompresor listrik yang sumber energinya berasal dari generator listrik.
6. Pasir bertekanan akan keluar melalui *nozzle*. Tekanan pasir pada ujung *nozzle* akan berkurang bergantung panjang selang yang digunakan. Semakin pendek selang maka semakin besar pula tekanannya.
7. Penggunaan *nozzle* tidaklah sembarangan. *Nozzle* tidak boleh diletakkan terlalu dekat dan tidak boleh terlalu jauh dengan plat yang akan di-*blasting*.
8. Plat yang terkena sandblasting akan mengikis. Pengikisan ini akan menumbulkan tekstur kasar yang sangat berpengaruh pada hasil pengecatan setelah *blasting*.
9. Setelah semua plat selesai di-*blasting* maka sebelum dilakukan pengecatan permukaan plat harus disemprotkan udara bertekanan guna menghilangkan debu-debu yang kemungkinan masih menempel pada permukaan plat.

### 3.2.4 Pengecekan Visual Hasil *Blasting*

Keadaan material pacsa-*blasting* perlu dipastikan apakah sudah sesuai standard yang digunakan atau belum. Tiap-tiap standard memiliki kriteria warna yang merupakan perwakilan dari identifikasi tingkat kebersihan material. Penelitian ini mengacu pada standard ISO 8501-1 - *Preparation of Steel Substrates Before Application of Paints and Related Products – Visual Assessment of Surface Cleanliness*. Pada standard ini terdapat beberapa tingkatan kebersihan, di antara adalah Sa-1, Sa-2, Sa-2 ½, dan Sa-3. Standard

Sa-3 dipilih karena merupakan tingkat kebersihan tertinggi yang ada pada ISO-8501-1. Oleh karena itu mengecek hasil *blasting* secara visual diperlukan untuk mengetahui apakah sudah sesuai tingkatan Sa-3 pada standar ISO 8501-1. Apabila belum sesuai dengan standar maka dilakukan *blasting* ulang. Berikut adalah gambar kebersihan permukaan Sa-3 ISO 8501-1.




**Gambar 3.3** Tingkat kebersihan permukaan Sa-3 ISO 8501-01
(Sumber: ISO 8501-01)

### 3.2.5 Mengukur Kekasaran Permukaan Hasil *Blasting*

Kekasaran permukaan merupakan salah satu hal yang mempengaruhi kualitas *coating*. Spesimen diukur kekasaran permukaannya dengan alat *roughness meter*. Pengujian ini mengacu standart ASTM D4417 - *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*. Bentuk alat *roughness meter* dapat dilihat pada gambar 3.4. Berikut adalah langkah-langkah melakukan pengukuran kekasaran sesuai standart ASTM D4417:

b. Menyiapkan peralatan pengukuran. Peralatan yang diperlukan yaitu *roughness meter* dan kaca datar untuk kalibrasi.
c. Mengkalibrasikan *roughness meter* dengan cara meletakannya di atas kaca hingga menunjuk angka 0.
d. Mengukur kekasaran permukaan dengan cara meletakkannya di atas permukaan spesimen.


**Gambar 3.4** *Roughness meter*

3.2.6 Proses Pelapisan dengan Cat *Epoxy*

Pelapisan dilakukan secara manual dengan menggunakan *air spray gun*. Cat yang digunakan yaitu *primer epoxy*. Ketebalan yang ingin dicapai adalah di atas standar BKI (250µm) dan di atas batas minimal saran ketebalan yang ada di *product data* cat (400µm). Berikut adalah langkah-langkah pelapisan:

a. Mempersiapkan cat yang akan digunakan dengan mencampur beberapa komponen cat dan mengaduknya hingga rata sempurna.
b. Memasukkan cat ke dalam tabung *air spray gun*.
c. Melakukan *spray* beberapa kali pada media lain (kertas) untuk mendapatkan konsistensi bentuk *spray*. Lakukan penyesuaian tekanan udara atau kekentalan cat apabila perlu.
d. Menempatkan spesimen pada *holder*, dan memegang *spray gun* dengan jarak 25-30 cm dari permukaan spesimen. Melakukan gerakan *spray* dengan kecepatan 25-40 cm/detik

3.2.7 Pengukuran Ketebalan Cat Basah

Pengukuran ketebalan dimaksudkan untuk mengetahui ketebalan cat ketika masih basah. Pabrik pembuat cat pasti memberi keterangan berapa penyusutan tebal cat setelah kering. Sehingga untuk mendapatkan tebal cat kering yang diinginkan, bisa mengacu pada tebal cat ketika masih basah. Pengukuran ketika cat masih basah dilakukan sesuai standar ASTM D4414 - *Standard Practice for Measurement of Wet Film Thickness by*

*Notch Gages*. Alat yang digunakan adalah *wet film thickness* (WFT) *gauge*. Bentuk alat yang disebut WFT ini dapat dilihat pada gambar berikut:


**Gambar 3.5** *Wet film thickness gauge* untuk uji WFT

Pengukuran menggunakan *wet film thickness* (WFT) dilakukan dengan cara berikut:

a. Menekan *wet film thickness gauge* tegak lurus pada permukaan spesimen.
b. Meletakan dan menggesekkan *wet film comb* di atas kertas lalu membaca ketebalan cat.
c. Apabila tidak ada cat yang menempel di antara dua ujung / kaki WFT, berarti cat lebih tipis daripada ukuran yang dicoba.
d. Apabila seluruh cat dari ujung ke unjung menempel keseluruhan, berarti cat lebih tebal daripada ukuran yang dicoba.
e. Ukuran tertinggi yang terkena cat adalah ukuran ketebalan cat basah.

### 3.2.8 Pengukuran Ketebalan Cat Kering

Pengukuran ketebalan cat kering ini dimaksudkan untuk mengetahui apakah ketebalan *coating* pada permukaan tiap-tiap spesimen sama atau ada perbedaan yang terlampau jauh. Hal ini perlu dilakukan karena pelapisan *coating* yang dilakukan secara manual dengan tangan manusia sangat rentan mengalami perbedaan ketebalan. Pengukuran ketika cat sudah kering dilakukan sesuai standar ASTM D4138 - *Standard Method of Measurement of Dry Film Thickness of Protective Coating Systems by*

*Destructive Means*. Alat yang digunakan adalah *coating thickness gauge*. Bentuk alat yang disebut *coating thickness gauge* ini dapat dilihat pada gambar berikut:


**Gambar 3.6** *Coating thickness gauge*.

Pengukuran menggunakan *coating thickness gauge* dilakukan dengan cara berikut:

e. Meletakan *coating thickness gauge* di 3 titik pada spesimen.
f. Mencatat angka yang ditunjukkan.
g. Melakukan perhitungan rata-rata untuk mendapatkan angka ketebalan kering cat.

### 3.2.9 Pengujian Daya Lekat

Pengujian daya lekat dilakukan sesuai standar ASTM D4541. Alat yang digunakan adalah *portable adhesive tester*. Bentuk alat yang disebut *portable adhesive tester* ini dapat dilihat pada gambar 3.7. Berikut adalah langkah-langkah pengujian sesuai standar ASTM D4541 - *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*:

a. Menyiapkan spesimen, *portable adhesive tester*, *dolly*, dan lem *epoxy*.
b. Melekatkan 3 *dolly* pada tiap spesimen menggunakan lem *epoxy*.
c. Menunggu hingga 1 x 24 jam atau lebih agar lem dapat kuat sempurna.
d. Mengkalibrasi *portable adhesive tester* hingga menunjukkan angka nol.
e. Menghubungkan *dolly* dengan *portable adhesive tester*.
f. Menekan tuas *portable adhesive tester* hingga *dolly* terlepas dari sampel.
g. Mencatat angka yang ditunjukkan.
h. Mengulangi ke seluruh *dolly* pada tiap-tiap spesimen.

i. Menghitung daya lekat rata-rata tiap-tiap spesimen.


**Gambar 3.7** Seperangkat *portable adhesive tester*

### 3.3 Rancangan Penelitian

Berdasarkan diagram alir penelitian, maka dapat dibuat rancangan penelitian untuk tiap tiap spesimen berikut:

**Tabel 3.1** Rancangan Penelitian

| Spesimen | Jenis Baja | Jenis Material Abrasif | Proses Blasting | Uji Visual Hasil Blasting | Uji Kekasaran Permukaan | Proses Coating | Uji Tebal Basah | Uji Tebal Kering | Uji Daya Lekat |
|---|---|---|---|---|---|---|---|---|---|
| A-1 | ASTM A36 | Steel Grid | v | v | v | v | v | v | v |
| A-2 | | Garnet | v | v | v | v | v | v | v |
| A-3 | | Silika | v | v | v | v | v | v | v |
| B-1 | ASTM A53 | Steel Grid | v | v | v | v | v | v | v |
| B-2 | | Garnet | v | v | v | v | v | v | v |
| B-3 | | Silika | v | v | v | v | v | v | v |

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# BAB IV

# HASIL PENELITIAN DAN PEMBAHASAN

# BAB IV
# HASIL PENELITIAN DAN PEMBAHASAN

## 4.1 Prosedur *Blasting* dan *Coating*

*Coating* dihipotesakan akan lebih besar daya lekatnya apabila permukaan material yang di-*coating* lebih tinggi nilai kekasarannya. Dalam penelitian ini dilakukan *blasting* untuk meningkatkan nilai kekasaran permukaan spesimen, sekaligus membersihkan permukaan spesimen dari zat pengotor lainnya sehingga diperoleh permukaan spesimen sesuai standart ISO 8501-1. Ada tiga jenis material abrasif yang digunakan untuk proses *blasting* ini, yaitu *steel grid*, garnet, dan silika. Proses *blasting* dilakukan dengan peralatan *Dry Abrasif Blast Cleaning*. Sedangkan proses *coating* dilakukan dengan peralatan *Airless Spray Coating*. Berikut adalah informasi bahan, alat, dan operator ketika proses *blasting* dilakukan.

### 4.1.1 Proses *Blasting* Pelat Baja A36 dan A53 dengan Material Abrasif *Steel Grid* dan *Coating Epoxy*

| | |
|---|---|
| *Blasting Operator* | : Aris (C.V. Cipta Agung) |
| *Coating* Operator | : Bombom (C.V. Cipta Agung) |
| Proses *Blasting* | : *Dry Abrasif Blast Cleaning* |
| Proses *Coating* | : *Airless Spray Coating* |
| Material 1 | : ASTM A36 |
| Material 2 | : ASTM A53 |
| Dimensi Material 1 | : 100 mm x 100 mm x 8 mm |
| Dimensi Material 1 | : 100 mm x 100 mm x 16 mm |
| Material Abrasif | : *Steel Grid* |
| Grit Material Abrasif | : Grit 16 |
| Tekanan Kompresor *Blasting* | : 5 bar |
| Jenis *Coating* | : Hempels Hempadur Multi-Strength GF 35870 |

### 4.1.2 Proses *Blasting* Pelat Baja A36 dan A53 dengan Material Abrasif *Steel Grid* dan *Coating Epoxy*

| | |
|---|---|
| *Blasting Operator* | : Aris (C.V. Cipta Agung) |

| | |
|---|---|
| *Coating Operator* | : Bombom (C.V. Cipta Agung) |
| Proses *Blasting* | : *Dry Abrasif Blast Cleaning* |
| Proses *Coating* | : *Airless Spray Coating* |
| Material 1 | : ASTM A36 |
| Material 2 | : ASTM A53 |
| Dimensi Material 1 | : 100 mm x 100 mm x 8 mm |
| Dimensi Material 1 | : 100 mm x 100 mm x 16 mm |
| Material Abrasif | : Garnet |
| Grit Material Abrasif | : Grit 16 |
| Tekanan Kompresor *Blasting* | : 5 bar |
| Jenis *Coating* | : Hempels Hempadur Multi-Strength GF 35870 |

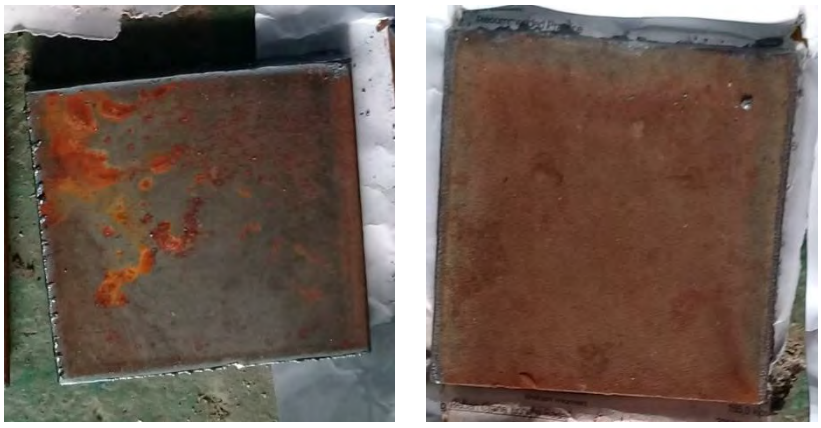
### 4.1.3 Proses *Blasting* Pelat Baja A36 dan A53 dengan Material Abrasif *Steel Grid* dan *Coating Epoxy*

| | |
|---|---|
| *Blasting Operator* | : Aris (C.V. Cipta Agung) |
| *Coating Operator* | : Bombom (C.V. Cipta Agung) |
| Proses *Blasting* | : *Dry Abrasif Blast Cleaning* |
| Proses *Coating* | : *Airless Spray Coating* |
| Material 1 | : ASTM A36 |
| Material 2 | : ASTM A53 |
| Dimensi Material 1 | : 100 mm x 100 mm x 8 mm |
| Dimensi Material 1 | : 100 mm x 100 mm x 16 mm |
| Material Abrasif | : Silika |
| Grit Material Abrasif | : Grit 16 |
| Tekanan Kompresor *Blasting* | : 5 bar |
| Jenis *Coating* | : Hempels Hempadur Multi-Strength GF 35870 |

## 4.2 Proses *Blasting*

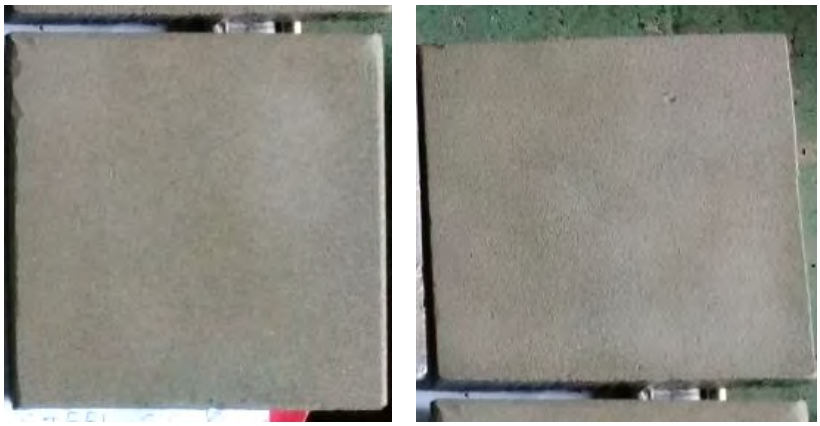
### 4.2.1 Hasil Proses *Blasting*

Proses *blasting* dilakukan sesuai metode *dry abrasive blast cleaning* yang mana lebih ekonomis dan hasilnya baik. Proses ini sangat penting karena menentukan kualitas *coating* apakah menempel dengan baik atau kurang. Dalam proses *blasting* ini dilakukan dengan variasi jenis material abrasif dan jenis material pelat yang digunakan. Material abrasif yang digunakan adalah jenis *steel grid*, garnet dan silika dengan grit 16. Material pelat yang digunakan adalah baja ASTM A36 dan A53. Tingkat kebersihan material yang ingin dicapai dalam proses ini adalah Sa-3 (ISO 8501-1). Berikut adalah keadaan material pelat sebelum dilakukan proses *blasting*:



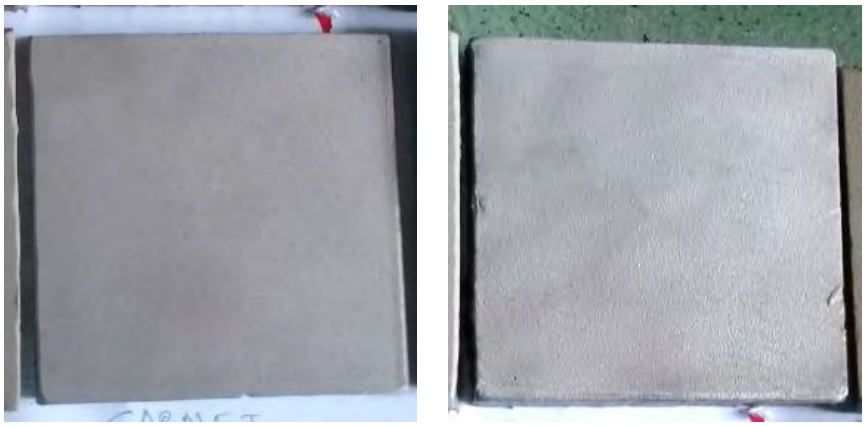
(a) (b)

**Gambar 4.1** Spesimen (a) A36 dan (b) A53 sebelum di-*blasting*.



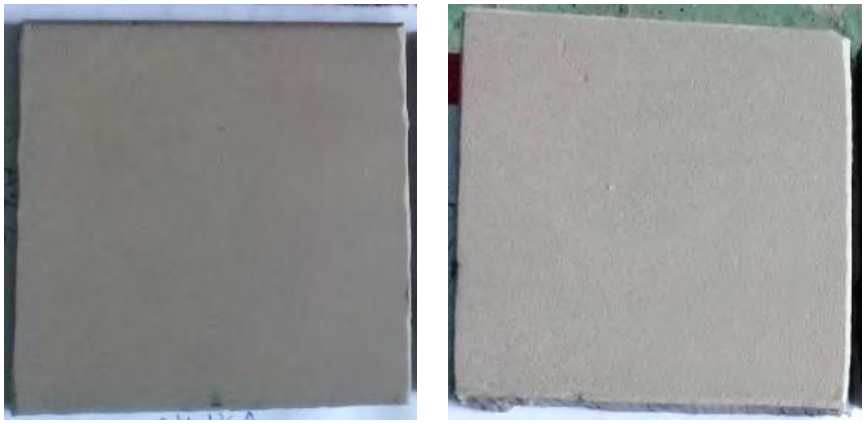
**Gambar 4.2** Spesimen (a) A36 dan (b) A53 setelah di-*blasting* dengan *steel grid*.

Pada gambar 4.1. di atas dapat dilihat bahwa pada permukaan pelat baja karbon ASTM A36 dan A53 yang belum di-*blasting*, warna baja terlihat hitam dan terdapat korosi. Gambar 4.2 adalah gambar pelat yang telah di-*blasting* dengan material abrasif jenis *steel grid*. Pada gambar 4.2 permukaan baja berubah drastis baik dari segi warna maupun kekasaran permukaannya. Demikian pula permukaan baja pada spesimen baja A36 dan A53 yang telah di-*blasting* dengan material abrasif jenis garnet (gambar 4.3) dan silika (gambar 4.4), warna dan kekasaran permukaannya berubah drastis.



(a) (b)

**Gambar 4.3** Spesimen (a) A-36 dan (b) A-53 setelah di-*blasting* dengan garnet.



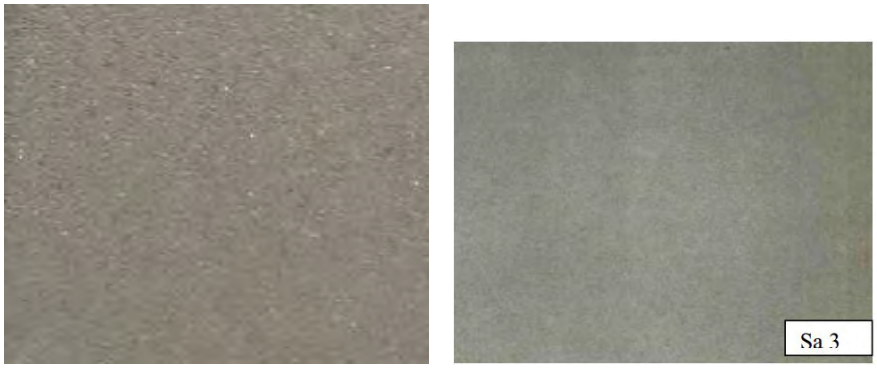
(a) (b)

**Gambar 4.5** Spesimen (a) A-36 dan (b) A-53 setelah di-*blasting* dengan silika.

Dari gambar 4.2, gambar 4.3, dan gambar 4.4 dapat dilihat bahwa pelat baja yang awalnya berwarna kehitam-hitaman dan terkorosi berubah warna menjadi abu-abu dan terlihat bersih tanpa ada zat yang mengotorinya (debu, air, korosi, dan lainnya). Profil permukaannya pun berubah yang awalnya kasar karena kotor dan terkorosi mejadi kasar yang bersih. Hal ini menunjukkan bahwa proses *blasting* efektif membersihkan permukaan material dari zat yang mengotorinya.

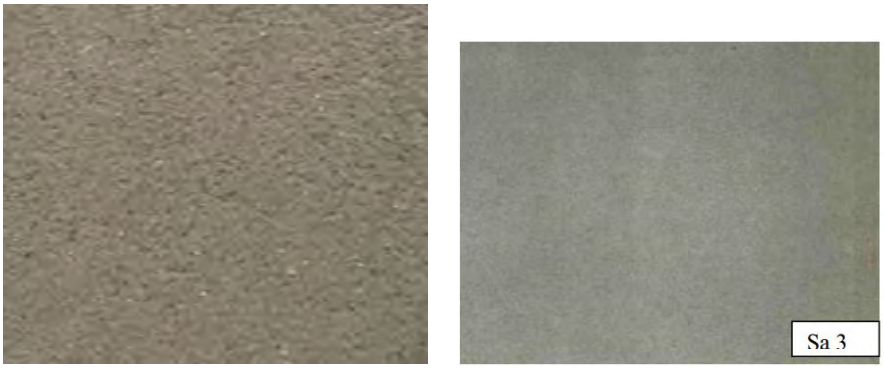
### 4.2.2 Inspeksi Visual Hasil *Blasting*

Inspeksi visual hasil *blasting* dilakukan untuk memastikan bahwa material yang telah di-*blasting* sesuai dengan tingkat kebersihan yang ingin dicapai yaitu Sa-3 pada standard ISO 8501-1 - *Preparation of Steel Substrates Before Application of Paints and Related Products – Visual Assessment of Surface Cleanliness*. Adapun cara untuk melakukan pengujian ini adalah dengan membandingkan material yang telah di-*blasting* dengan gambar yang ada di standard ISO 8501-1. Hasil inspeksi visual tiap-tiap spesimen dapat dilihat pada gambar dibawah ini.




(a) (b)

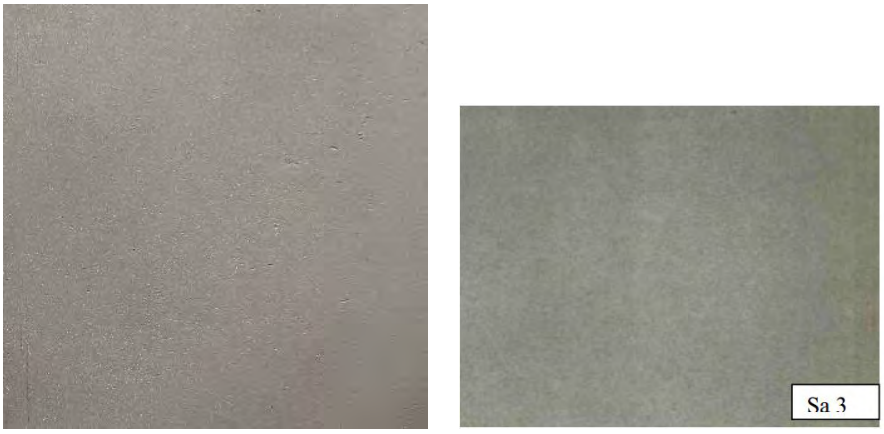
**Gambar 4.6** (a) Baja ASTM A36 yang telah di-*blasting* dengan *steel grid*, (b) standard Sa-3 (ISO-8501-1)




(a) (b)

**Gambar 4.7** (a) Baja ASTM A53 yang telah di-*blasting* dengan *steel grid* (b) standard Sa-3 (ISO-8501-1).

Pada gambar 4.6 dan gambar 4.7 di atas dapat kita ketahui bahwa warna permukaan pelat baja ASTM A-36 dan A-53 tidak jauh berbeda dengan warna pada gambar standard Sa-3 (ISO-8501-1). Sehingga dapat dinyatakan bahwa baja ASTM A36 dan A53 yang telah di-*blasting* dengan *steel grid* telah lolos uji visual hasil *blasting*.



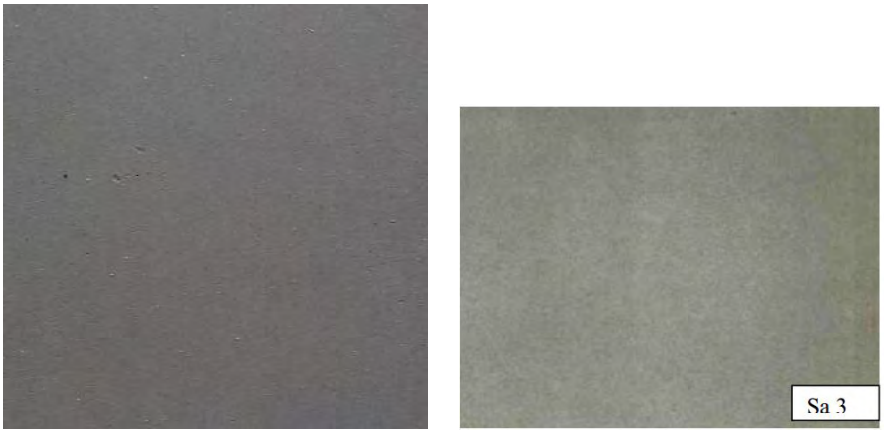

(a) (b)

**Gambar 4.8** (a) Baja ASTM A36 yang telah di-*blasting* dengan garnet (b) standard Sa-3 (ISO-8501-1).


(a) (b)

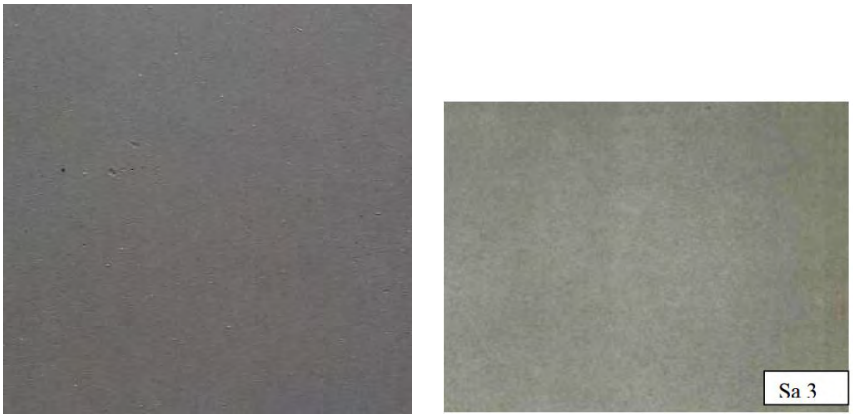
**Gambar 4.9** (a) Baja ASTM A53 yang telah di-*blasting* dengan garnet (b) standard Sa-3 (ISO-8501-1).

Pada gambar 4.8 dan 4.9 di atas dapat kita ketahui bahwa warna permukaan pelat baja ASTM A36 dan A53 juga tidak jauh berbeda dengan warna pada gambar standard Sa-3 (ISO-8501-1). Sehingga dapat dinyatakan bahwa baja ASTM A36 dan A53 yang telah di-*blasting* dengan garnet telah lolos uji visual hasil *blasting*.




(a) (b)

**Gambar 4.10** (a) Baja ASTM A-36 yang telah di-*blasting* dengan silika (b) standard Sa-3 (ISO-8501-1).




(a) (b)

**Gambar 4.11** (a) Baja ASTM A-36 yang telah di-*blasting* dengan silika (b) standard Sa-3 (ISO-8501-1).

Pada gambar 4.10 dan gambar 4.11 di atas dapat kita ketahui bahwa warna permukaan pelat baja ASTM A36 dan A53 juga tidak jauh berbeda dengan warna pada gambar standard Sa-3 (ISO-8501-1). Sehingga dapat dinyatakan bahwa baja ASTM A36 dan A53 yang telah di-*blasting* dengan silika juga telah lolos uji visual hasil *blasting*.

Pada tingkat kebersihan SA-3 ini material telah sangat minim kontaminan baik dari minyak, debu, karat, maupun bekas cat. Dari inspeksi visual hasil *blasting* dapat dilihat bahwa tiap-tiap spesimen telah mencapai tingkat kebersihan permukaan Sa-3 ISO 8501-01. Sehingga dapat dinyatakan bahwa seluruh spesimen lolos uji visual. Lalu selanjutnya dilakukan uji kekasaran permukaan.

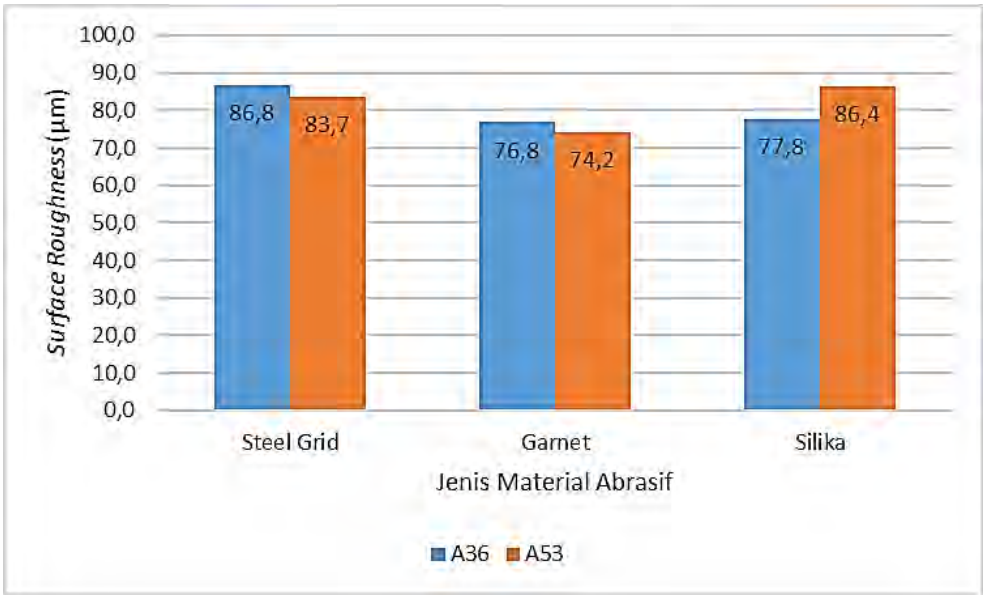
## 4.3 Pengujian Kekasaran Permukaan

### 4.3.1 Hasil Pengujian Kekasaran Permukaan

Setelah proses inspeksi visual, spesimen diukur kekasaran permukaannya menggunakan *roughness meter*. Pengujian ini dilakukan untuk mengetahui kedalaman profil pada material yang telah di-*blasting*. Pengujian ini perlu dilakukan karena merupakan salah satu faktor yang diteliti pengaruhnya terhadap kualitas *coating*. Hasil pengujian nilai kekasaran permukaan dapat dilihat pada tabel 4.1 dan gambar 4.16 di bawah ini.

**Tabel 4.1** Hasil pengujian kekasaran permukaan.

| Material Pelat | Material Abrasif | Nilai Kekasaran Permukaan (µm) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | Rata-rata |
| ASTM A36 | *Steel Grid* | 91,5 | 90 | 79 | 86,8 |
| | Garnet | 80,3 | 80,1 | 70,1 | 76,8 |
| | Silika | 81,5 | 83,8 | 68 | 77,8 |
| ASTM A53 | *Steel Grid* | 87,7 | 84 | 79,3 | 83,7 |
| | Garnet | 80 | 72,5 | 70 | 74,2 |
| | Silika | 87,2 | 93,9 | 78 | 86,4 |




**Grafik 4.1** Nilai rata-rata kekasaran permukaan pelat baja A36 dan A53.

Pada tabel 4.1 di atas, nilai rata-rata kekasaran permukaan tertinggi pada pelat ASTM A36 didapatkan dengan material abrasif jenis *steel grid* yang mana mampu mencapai angka 86,8 µm. Lalu disusul oleh silika dan garnet dengan nilai rata-rata kekasaran permukaan masing-masing mencapai 77,8 dan 76,8. Meskipun *steel grid* memiliki nilai kekasaran sekitar 4 hingga 4,5 skala mohs yang tentu lebih rendah dibanding garnet dan silika yang memiliki nilai kekasaran 8,5 dan 7 pada skala mohs, ternyata menghasilkan nilai kekasaran permukaan yang paling tinggi. Sedangkan pada pelat ASTM A53, nilai rata-rata kekasaran permukaan tertinggi mencapai 86,4 didapatkan dengan material abrasif jenis silika. Lalu disusul steel grid dan garnet dengan nilai rata-rata kekasaran permukaan masing-masing 83,7 dan 74,2 pada skala mohs.

Hasil pengujian di atas menunjukan bahwa penggunaan material abrasif yang berbeda saat proses *blasting* menghasilkan nilai rata-rata yang berbeda pula. Material abrasif yang menghasilkan nilai rata-rata kekasaran permukaan tertinggi pada suatu material pelat ternyata tidak menghasilkan nilai rata-rata kekasaran permukaan tertinggi pada material pelat lainnya. Hal ini sejalan dengan teori yang mendasari penelitian ini bahwa perbedaan material abrasif yang digunakan ketika proses *blasting* menghasilkan nilai kekasaran permukaan yang berbeda dan suatu material pelat yang cocok dengan material abrasif tertentu, belum tentu tidak cocok dengan material abrasif lainnya. Hal ini terjadi karena tiap-tiap material pelat dan material abrasif terbentuk dari zat penyusun yang berbeda-beda. Di bawah ini adalah grafik perbandingan antara nilai rata-rata kekasaran permukaan pada pelat ASTM A36 dan A53 yang di-*blasting* dengan material jenis *steel grid*, garnet, dan silika.

### 4.3.2 Kesimpulan dari Pengujian Kekasaran Permukaan

Tiap-tiap material abrasif menghasilkan kekasaran permukaan yang bervariasi dan kekasaran dalam satu bidang pelat tidak sama, sehingga hanya dapat dilakukan pendekatan nilai kekasaran. Pada penelitian ini diambil nilai kekasaraan permukaan dengan menghitung nilai rata-rata dari pengujian yang dilakukan sebanyak 3 kali tiap spesimen. Dari pendekatan nilai kekasaran didapat tingkat kekasaran tertinggi pada pelat ASTM A36 dihasilkan oleh material abrasif jenis *Steel Grid* sedangkan pada pelat ASTM A53 dihasilkan oleh material abrasif jenis Silika.

## 4.4 Proses *Coating*

Selain proses persiapan permukaan, faktor lain yang menentukan baik dan buruknya pengecatan adalah keahlian dan pengalaman dari operator. Pada proses pengecatan ada beberapa hal utama yang perlu diperhatikan, diantaranya yaitu:

1. Material Cat

   Dalam penelitian ini hanya dilakukan proses aplikasi *coating primer*. Penulis menggunakan cat *primer* jenis *epoxy* Hempel's Hempadur Multi-Strength GF35870.

2. *Mixing Ratio*

   *Mixing Ratio* merupakan perbandingan antara cat dengan pengeringnya (*hardener*). Perbandingan dapat dilihat pada *product data* cat (terlampir). Untuk cat *primer epoxy* Hempel's Hempadur Multi-Strength GF35870 rasio perbandingan antara *part* A yaitu *base* 35879 dan *part* B *curing agent* 98870 adalah 3:1. Sedangkan untuk penambahan *thinner* karena menggunakan *air spray gun*, *thinner* yang digunakan secukupnya atau maksimal 5%.

3. *Volume Solid*

   *Volume solid* adalah persentase dari tebal lapisan cat pada saat kering terhadap lapisan cat pada saat basah. *Volume solid* dapat dilihat di *product data* (terlampir). *Volume solid* berperan penting dalam menentukan ketebalan lapisan cat basah maupun kering yang akan dicapai. Menurut *product data*, *volume solid* dari cat primer jenis *epoxy* (Hempel's Hempadur Multi-Strength GF35870) adalah 87%.

4. *Curing Time*

   *Curing time* merupakan waktu yang dibutuhkan cat untuk mengering, ada 3 jenis *curing time* pada cat yaitu:

   - *Full cured*: Waktu yang dibutuhkan suatu lapisan cat untuk mencapai kondisi kering sepenuhnya.
   - *Dry to touch*: Waktu yang dibutuhkan oleh lapisan cat untuk mencapai kondisi permukaan cukup kering bila disentuh.
   - *Dry to handle*: Kondisi permukaan lapisan cat di mana baja yang dicat dapat diangkut atau dipindahkan tanpa menyebabkan terjadinya kerusakan lapisan cat yang berarti.

5. Air Spray Gun

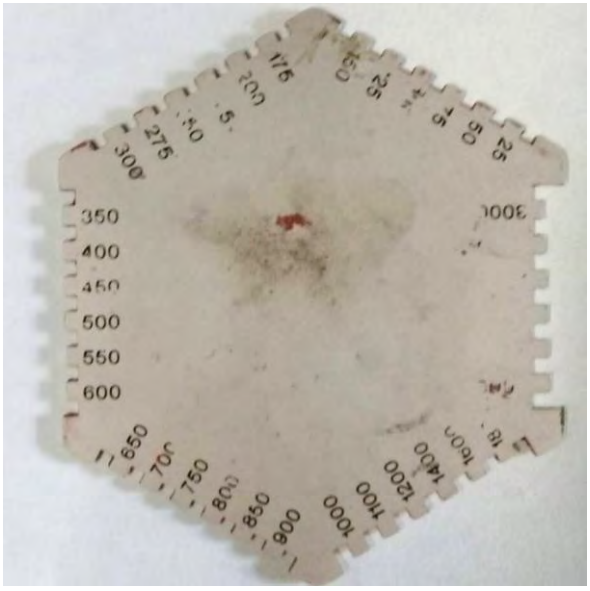
   Pada penelitian ini proses *coating* dilakukan dengan metode *air spray gun*, kelebihan dari penggunaan metode ini antara lain :

   - Atomisasi cat lebih lembut, sehingga hasil pengecatan lebih halus.
   - Penggunaan peralatan ini sangat mudah karena pengatur pengontrol cat, kelebaran sudut semprot, dan volume angin terletak pada *spray gun*.

- Lebih ekonomis.
- Bisa digunakan untuk pengecatan bertekstur.
- Untuk mengganti warna cat dapat dengan mudah dilakukan dengan hanya mengganti *suction cup*.

## 4.5 Pengujian *Wet Film Thickness* (WFT)

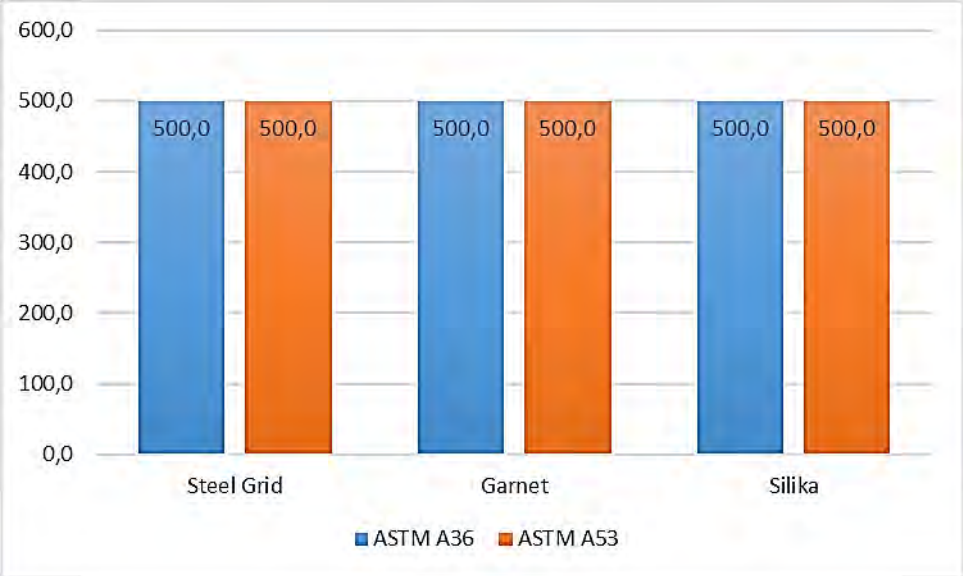
Pengujian *Wet Film Thickness* (WFT) dilakukan menggunakan *WFT Comb*. Pengujian dilakukan dengan menekan alat ke atas permukaan cat yang masih basah lalu menekan dan menyeret alat di atas kertas untuk mengetahui nilai hasil uji. Dari pengujian yang dilakukan didapatkan ketebalan cat basah tiap-tiap spesimen (lihat tabel 4.2). Keseragaman nilai uji WFT ini menentukan apakah pengujian dapat dilanjutkan atau tidak, dikarenakan pada pengujian ini dilakukan perbandingan, sehingga nilai uji WFT harus sama. Pada tabel 4.2 di bawah, nilai uji WFT tiap-tiap spesimen tertera 500 µm.




**Gambar 4.12** *Wet film thickness (WFT) gauge* yang digunakan

**Tabel 4.2** Hasil pengujian *Wet Film Thickness* (WFT).

| Material Pelat | Material Abrasif | Nilai Uji WFT (µm) | Gambar |
|---|---|---|---|
| ASTM A36 | *Steel Grid* | 500 |  |
| | Garnet | 500 |  |
| | Silika | 500 |  |
| ASTM A53 | *Steel Grid* | 500 |  |
| | Garnet | 500 |  |
| | Silika | 500 |  |



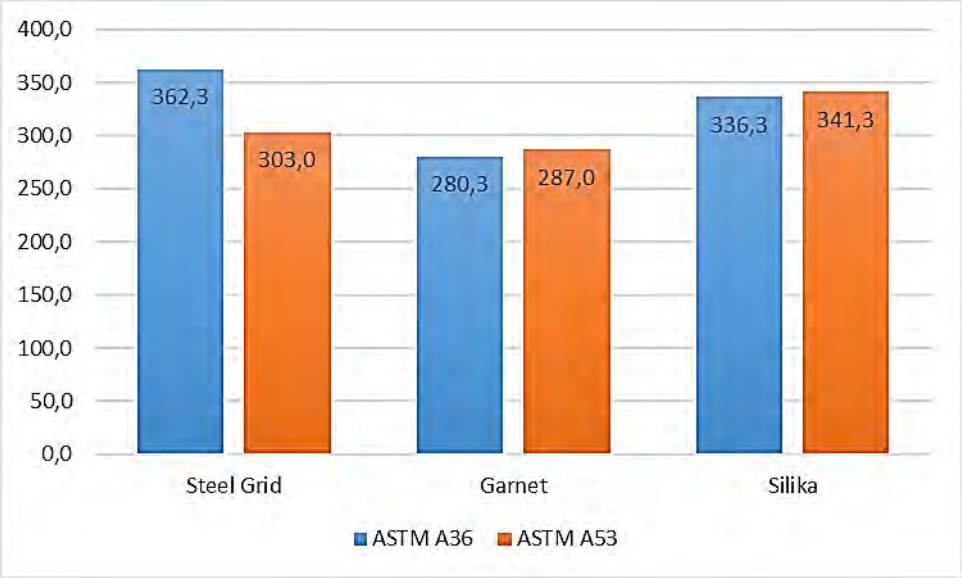

**Grafik 4.2** Hasil pengujian *Wet Film Thickness (WFT)*

## 4.6 Pengujian *Dry Film Thickness*

Pengujian *dry film thickness* dilakukan beberapa kali lalu diambil 3 sampel yang dianggap mewakili dari tiap-tiap spesimen dan diambil nilai rata-ratanya. Nilai *dry film thickness* sangat sulit untuk dibuat sama persis, sehingga adanya selisih ketebalan tidak dapat dihindari. Pada hasil pengujian ini nantinya apabila terdapat hasil yang diperoleh, kemungkinan faktor penyebabnya adalah nilai uji DFT berikut yang tidak sama persis nilainya. Nilai rata-rata hasil pengujian DFT dapat dilihat pada tabel berikut:

**Tabel 4.3** Hasil pengujian *Dry Film Thickness* (DFT)

| Material Pelat | Material Abrasif | Nilai Uji DFT (µm) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | Rata-rata |
| ASTM A36 | *Steel Grid* | 368 | 367 | 352 | 362,3 |
| | Garnet | 329 | 308 | 317 | 318,0 |
| | Silika | 334 | 326 | 349 | 336,3 |
| ASTM A53 | *Steel Grid* | 335 | 328 | 330 | 331,0 |
| | Garnet | 339 | 324 | 314 | 325,7 |
| | Silika | 350 | 335 | 339 | 341,3 |




**Grafik 4.3** Hasil pengujian *Dry Film Thickness (DFT)*

## 4.7 Pengujian Daya Lekat

Setelah dilakukan pengujian *dry film thickness*, dilakukan pengujian daya lekat terhadap spesimen. Pengujian daya lekat dilakukan untuk mengukur kekuatan daya lekat cat dengan antara lapisan cat dengan substrat. Standart yang digunakan untuk pengujian ini adalah ASTM D4541-02. Menurut standar NORSOK M-501, syarat nilai kekuatan adhesi minimum yaitu 5 MPa.

Ada beberapa metode yang dapat digunakan dalam pengujian daya lekat antara lain metode *X-cut tape test*, metode *cross-cut tape test*, dan metode *pull-off test*. Dalam penelitian ini digunakan metode *pull-off test*. Untuk melakukan pengujian ini hal yang harus dilakukan adalah menempelkan 3 pin *dolly* menggunakan lem *epoxy* sehari sebelum dilakukan pengujian, hal ini dimaksudkan agar pin *dolly* menempel sempurna ke

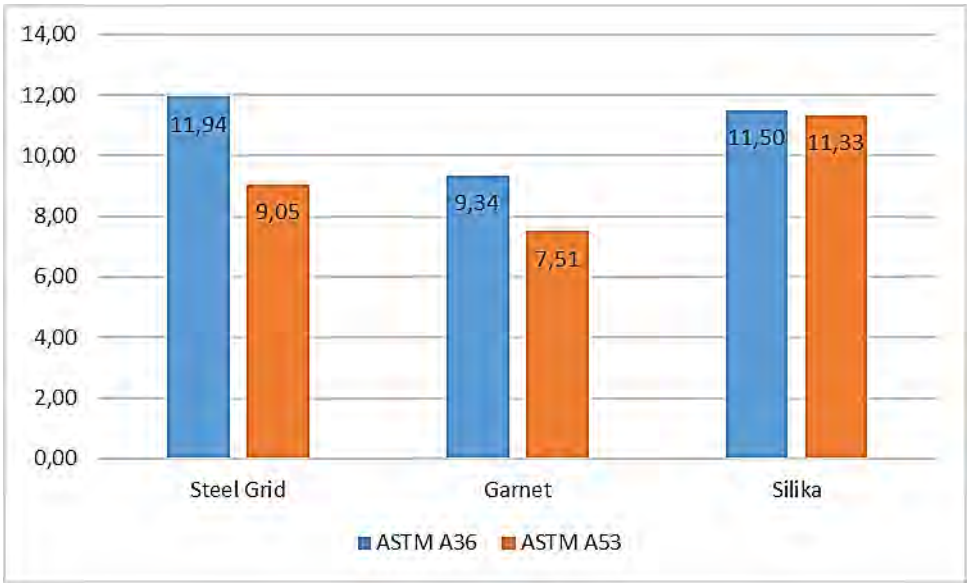
spesimen. Setelah pin *dolly* menempel dengan sempurna, lepaskan sisa lem *epoxy adhesive* dari sisi *dolly* dengan menggunakan *dolly cutter*, letakkan piringan (*base support ring*) untuk dudukan *adhesion tester*, dan tarik *dolly* dengan menekan tuas pada alat *adhesion tester* hingga *dolly* terlepas. Angka yang ditunjukkan pada alat *adhesion tester* merupakan nilai daya lekat *coating.*


**Gambar 4.13** Spesimen yang telah dilekatkan pin *dolly*.

**Gambar 4.14** Pengujian daya lekat *coating*.

**Tabel 4.4** Hasil Pengujian Daya Lekat

| Material Pelat | Material Abrasif | Nilai Uji Daya Lekat (MPa) | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | Rata-rata |
| ASTM A36 | *Steel Grid* | 13,98 | 10,99 | 10,85 | 11,9 |
| | Garnet | 9,15 | 10,84 | 8,03 | 9,3 |
| | Silika | 13,81 | 10,65 | 10,05 | 11,5 |
| ASTM A53 | *Steel Grid* | 9,68 | 9,44 | 8,03 | 9,1 |
| | Garnet | 8,90 | 7,55 | 6,07 | 7,5 |
| | Silika | 10,53 | 13,20 | 10,27 | 11,3 |




**Grafik 4.4** Hasil Pengujian Daya Lekat *Coating*

Dari tabel 4.4 dan grafik 4.4 di atas dapat diketahui bahwa pada pelat baja ASTM A36, nilai daya lekat tertinggi dicapai oleh pelat baja yang di-*blasting* menggunakan *steel grid* dengan nilai daya lekat mencapai 11,94 MPa. Lalu pada urutan kedua dan ketiga adalah silika dan garnet dengan nilai daya lekat masing-masing 11,50 MPa dan 9,34 MPa. Sedangkan pada pelat baja ASTM A53 nilai daya lekat tertinggi dicapai oleh pelat baja yang di-*blasting* menggunakan silika dengan nilai daya lekat 11,33 MPa. Disusul oleh *steel grid* dan silika dengan nilai daya lekat masing-masing 9,05 MPa dan 7,51 MPa.

Bentuk lapisan antara cat dengan pelat dapat dilihat menggunakan foto makro dan mikro dengan pengambilan foto dari arah samping. Sebelum diambil foto makro dan mikro, terlebih dahulu pelat baja ini dipotong yang awalnya berukuran panjang 10 cm

dan lebar 10 cm menjadi kurang lebih sekitar 5 cm x 1 cm. Pemotongan ini bertujuan agar supaya material dapat masuk ke area foto yang berada di bawah mikroskop. Setelah dipotong, area yang akan difoto dipoles (dihaluskan) menggunakan ampelas mulai dari grid 200 hingga 2000 lalu diberi cairan *etsa*. Berikut adalah tabel foto makro dan mikro tiap-tiap material:

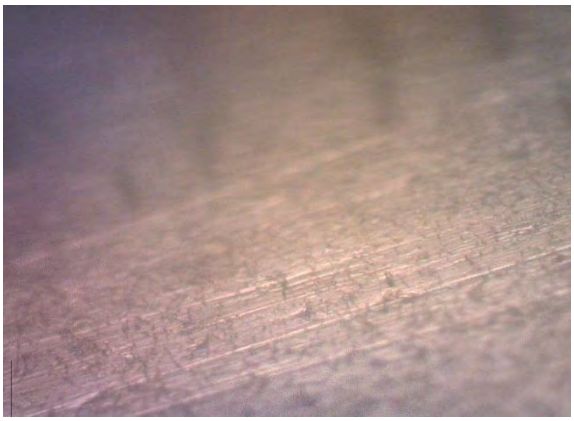
**Tabel 4.5** Foto Makro

| No. | Material | Foto Makro |
|---|---|---|
| 1 | Baja A36, *Steel grid* |  |
| 2 | Baja A36, Garnet |  |
| 3 | Baja A36, Silika |  |
| 4 | Baja A53, *Steel Grid* |  |
| 5 | Baja A53, Garnet |  |

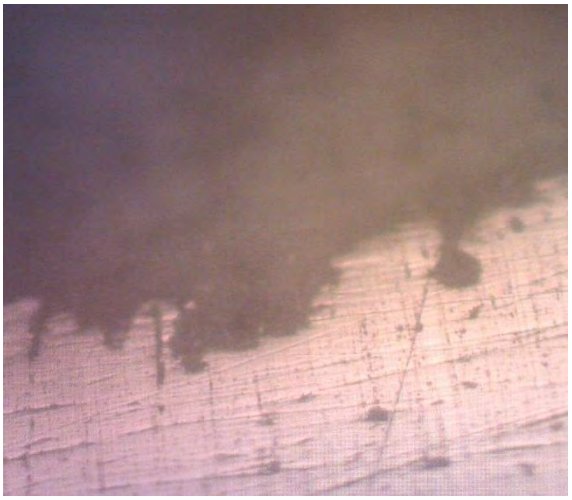
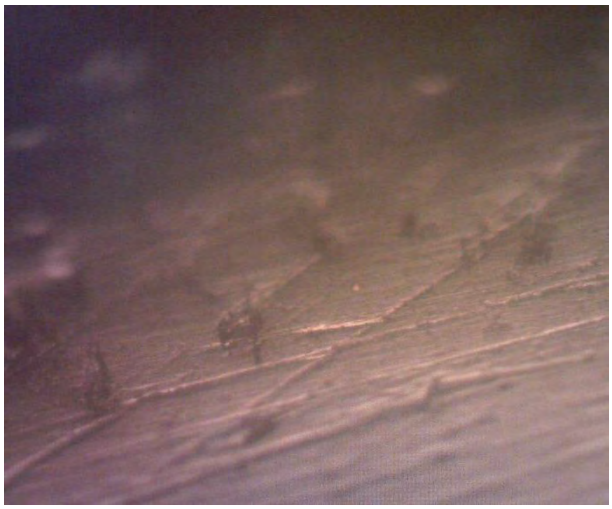
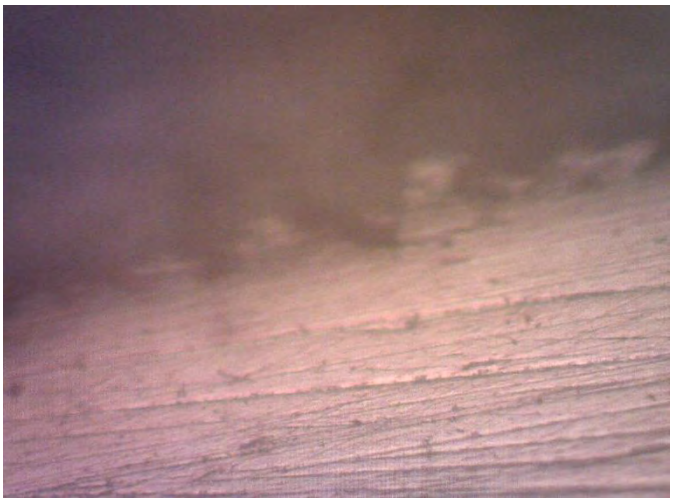
**Tabel 4.6** Foto Makro (lanjutan)

| **No.** | **Material** | **Foto Makro** |
|---|---|---|
| 6 | Baja A53, Silika |  |

**Tabel 4.7** Foto Mikro

| No. | Material | Foto Mikro |
|---|---|---|
| 1 | Baja A36, *Steel grid* |  |
| 2 | Baja A36, Garnet |  |

**Tabel 4.8** Foto Mikro (lanjutan 1)

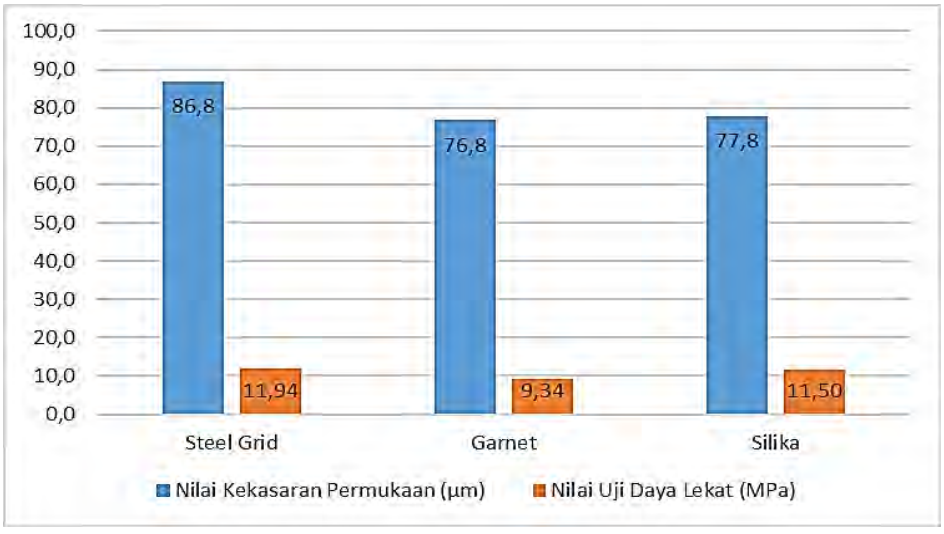
| | | |
|---|---|---|
| 3 | Baja A36, Silika |  |
| 4 | Baja A53, *Steel Grid* |  |
| 5 | Baja A53, Garnet |  |

**Tabel 4.9** Foto Mikro (lanjutan 2)

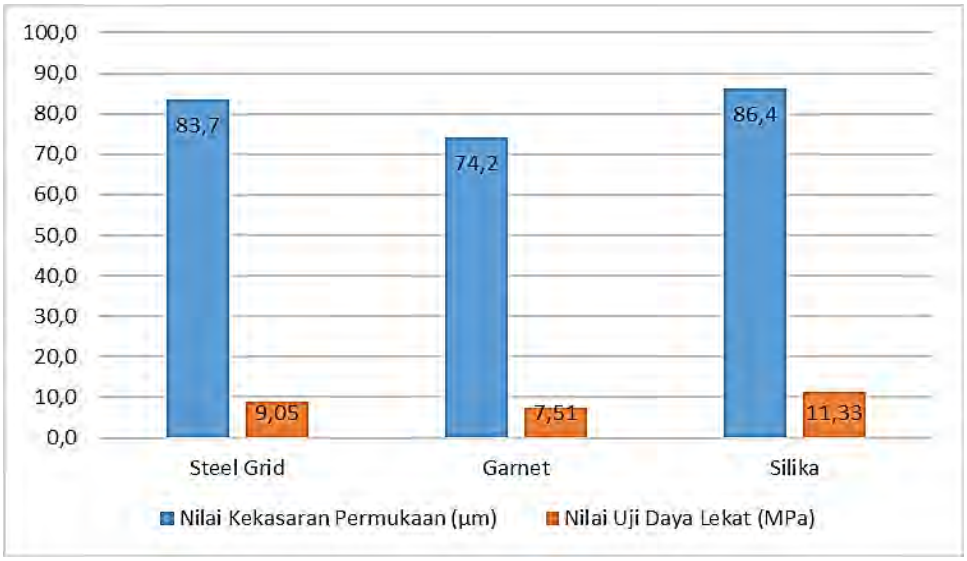
| No. | Material | Foto Mikro |
|---|---|---|
| 6 | Baja A53, Silika |  |

## 4.8 Korelasi Antara Jenis Material Abrasif, Nilai Kekasaran Permukaan dan Nilai Daya Lekat

Material abrasif yang berbeda menghasilkan profil permukaan yang berbeda pula. Nilai kekasaran permukaan didapatkan menggunakan *roughness meter*. Sedang daya lekat salah satunya dipengaruhi oleh nilai kekasaran permukaan. Maka di sini terdapat korelasi atau hubungan antara jenis material abrasif, nilai kekasaran permukaan pelat baja dan nilai daya lekat yang didapat. Berikut ini adalah grafik yang menunjukkan hubungan ketiganya.




**Grafik 4.5** Nilai kekasaran permukaan dan nilai uji daya lekat pada baja A36




**Grafik 4.6** Nilai kekasaran permukaan dan nilai uji daya lekat pada baja A53

Dari grafik di atas jelas dapat diketahui bahwa nilai kekasaran permukaan mempengaruhi nilai daya lekat *coating*. Semakin tinggi nilai kekasaran permukaan, semakin tinggi pula daya lekat *coating*. Hal ini sejalan dengan hipotesa dan dasar penelitian ini. Semakin tinggi nilai daya lekat, berarti semakin baik pula kualitas *coating*. Meskipun material abrasif yang digunakan sama, nilai kekasaran permukaan antara pelat ASTM A36 dan A53 tidaklah sama. Hal ini dikarenakan tingkat kekerasan dan kegetasan material abrasif berbeda. Material abrasif dengan tingkat kekerasan dan kegetasan terntentu akan cocok digunakan untuk material pelat dengan tingkat kekerasan dan kegetasan tertentu pula. Dari penelitian ini didapat bahwa pelat ASTM A36 lebih cocok menggunakan material abrasif jenis *steel grid*, sedangkan pelat ASTM A53 lebih cocok menggunakan material abrasif jenis silika.

Penelitian ini menggunakan material abrasif baru, namun kenyataan di lapangan, untuk menghemat biaya *blasting*, maka digunakan material abrasif bekas (*re-use*). Pada tahun 2010, Susetyo telah melakukan penelitian mengenai biaya yang timbul untuk berlangsungnya proses *blasting*, baik jika menggunakan material abrasif baru maupun lama (*re-use*). Material yang diteliti antara lain: *volcanic sand*, silika, garnet, *steel grid*, *copper slag*, dan *crushed glass*. Penelitian tersebut dilakukan dengan objek yang di-*blasting* berupa kapal dengan luasan 1359,93 $m^2$. Dari penelitian tersebut, penulis sajikan tabel rangkuman perbandingan konsumsi material abrasif baru per $m^2$, lama pengerjaan, dan perkiraan harga material abrasif baru per kilogram.

**Tabel 4.10** Perbandingan konsumsi material abrasif baru per $m^2$, lama pengerjaan, dan perkiraan harga material abrasif baru per kilogram.

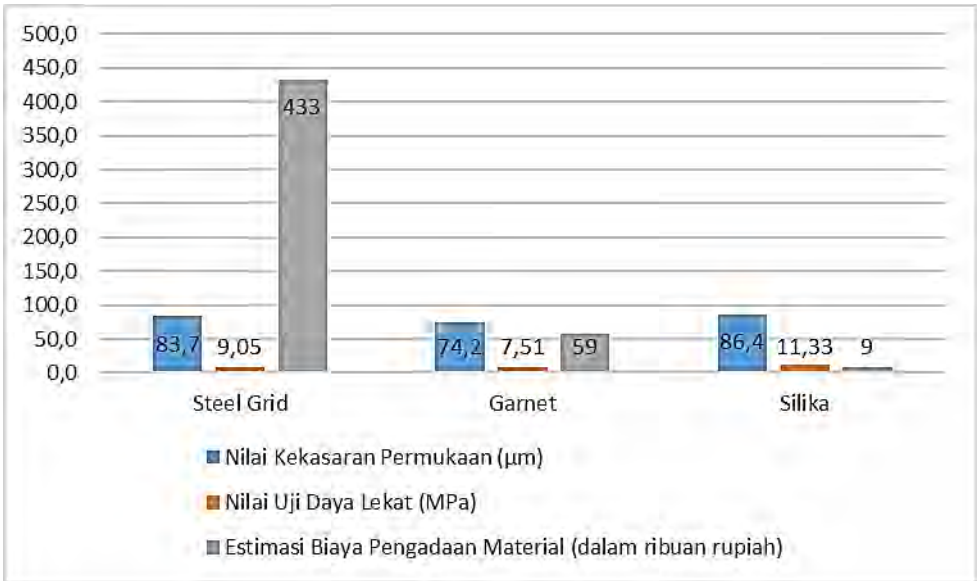
| Jenis Material Abrasif | Konsumsi Material Abrasif ($kg/m^2$) | Kecepatan Pengerjaan ($m^2$/jam) | Estimasi Harga Material per Kg |
|---|---|---|---|
| Steel Grid | 27,5 | 16,56 | Rp15.750 |
| Garnet | 13,0 | 25,65 | Rp4.500 |
| Silika | 18,0 | 19,17 | Rp500 |

Dari tabel di atas diketahui estimasi biaya pembelian material baru tiap-tiap material abrasif. Proses *blasting* menggunakan material abrasif *steel grid* menghabiskan sekitar 27,5 kg tiap $m^2$, ini paling banyak dibandingkan dengan garnet dan silika. Garnet dan silika menghabiskan masing-masing 13 kg dan 18 kg per $m^2$. Ini tentu berpengaruh terhadap biaya pengadaan material. Untuk 1 $m^2$ *blasting* dengan *steel grid* dibutuhkan biaya pengadaan material sebanyak 27,5 x 15.750 = Rp433.125,00. Untuk 1 $m^2$ *blasting* dengan garnet dibutuhkan biaya pengadaan material sebanyak 13 x 4.500 = Rp58.500,00. Untuk 1 $m^2$ *blasting* dengan silika dibutuhkan biaya pengadaan material sebanyak 18 x 500 = Rp9.000,00. Ternyata *steel grid* yang biaya pengadaan materialnya paling mahal. Lalu disusul garnet dan kemudian silika. Kecepatan pengerjaan juga berpengaruh pada biaya untuk menggaji operator *blasting*. Dari ketiga material tersebut, kecepatan pengerjaan tertinggi didapat dari material abrasif jenis garnet yang mencapai 25,65 $m^2$ per jam. Lalu disusul silika dan *steel grid* dengan kecepatan masing-masing 19,17 $m^2$ per jam dan 16,56 $m^2$ per jam.

Selanjutnya dibandingkan dengan nilai kekasaran permukaan dan daya lekat yang didapat. Maka akan terlihat korelasi antara nilai kekasaran permukaan dan daya lekat serta estimasi biayanya. Berikut ini adalah grafik rangkuman dari nilai kekasaran permukaan, nilai daya lekat, dan estimasi biaya pengadaan material abrasif.


**Grafik 4.7** Nilai kekasaran permukaan, nilai daya lekat, dan estimasi biaya pengadaan material abrasif untuk pelat baja A36

Dari grafik di atas sangat jelas terlihat bahwa untuk pelat baja A36, material abrasif yang menghasilkan kualitas *coating epoxy* terbaik adalah *steel grid*, namun biaya pengadaan material abrasifnya sangat tinggi, jauh di atas biaya pengadaan material abrasif lainnya.




**Grafik 4.8** Nilai kekasaran permukaan, nilai daya lekat, dan estimasi biaya pengadaan material abrasif untuk pelat baja A53

Dari grafik di atas terlihat pula bahwa untuk pelat baja A53, material abrasif yang menghasilkan kualitas *coating epoxy* terbaik adalah silika, dan biaya pengadaan material abrasifnya paling rendah, paling hemat biaya.

# BAB V

# KESIMPULAN DAN SARAN

# BAB V
# KESIMPULAN DAN SARAN

## 5.1 Kesimpulan

Setelah dilakukan analisis hasil pengujian, maka dapat diambil kesimpulan dari penelitian yang dilakukan. Berikut kesimpulannya:

1. Semakin tinggi nilai kekerasan partikel abrasif yang digunakan untuk proses *blasting*, maka akan semakin tinggi nilai kekasaran permukaan yang didapat. Namun kekerasan partikel abrasif juga harus diimbangi dengan sifat getasnya. Pada material pelat A36 yang lebih lunak daripada A53, partikel abrasif *steel grid* menghasilkan kekasaan permukaan yang paling tinggi (86,8 μm) dengan nilai daya lekat rata-rata 11,9 MPa. Sedangkan pada material pelat A53, partikel abrasif silika menghasilkan kekasaan permukaan yang paling tinggi (86,4 μm) dengan nilai daya lekat rata-rata 11,3 MPa.

2. Semakin tinggi kekasaran permukaan akan meningkatkan nilai daya lekat cat dengan pelat. Hal ini ditunjukkan dengan nilai daya lekat cat yang menempel pada pelat. Pada pelat A53 dengan nilai rata-rata kekasaran permukaannya 74,2 μm (garnet) memiliki daya lekat 7,5 MPa. Sedangkan yang nilai rata-rata kekasaran permukaannya 86,4 μm memiliki daya lekat 11,3 MPa (silika).

3. Pada pelat A36, partikel *steel grid* lebih bagus karena menghasilkan kekasaran permukaan paling tinggi, namun biaya *blasting* sangat tinggi (Rp433.125,00 per $m^2$). Sedang pada pelat A53, partikel silika lebih bagus dan hemat biaya *blasting* (Rp9.000,00 per $m^2$).

## 5.2 Saran

Untuk penelitian lebih lanjut sehingga dapat melengkapi penelitian ini dapat dilakukan penelitian berikut:

1. Melakukan penelitian lebih lanjut dengan membandingkan hasil yang didapat dari penggunaan material abrasif baru dan bekas (*re-use*)..

# DAFTAR PUSTAKA

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Afandi, Y.K., Arief, I.S., Amiadji. 2015. *Analisa Laju Korosi pada Pelat Baja Karbon dengan Variasi Ketebalan Coating*. Jurnal Teknik ITS Vol. 4 No.1.

Anusavice, KJ. *Phillips' Science of Dental Materials*. Trans. Johan Arief Budiman dan Susi Purwoko. 10th ed., Jakarta: EGC, 2004 : 197-223.

ASTM D4414. 1996. *Standard Practice for Measurement of Wet Film Thickness by Notch Gages*. Annual Book of ASTM Standards.

ASTM D4138. 2001. *Standard Test Methods for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means*. Annual Book of ASTM Standards.

ASTM D4541-02. 2002. *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*. Annual Book of ASTM Standards.

ASTM D4417–03. 2003. *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*. Annual Book of ASTM Standards.

ASTM G31-72. 2004. *Standard Practice for Laboratory Immersion Corrosion Testing of Metals*. Annual Book of ASTM Standards.

Bermont-Bouis, D., M. Janvier, P.A.D. Grimont, I. Dupont and T. Vallaeys. 2007. *Both Sulfate Reducing Bacteria and Enterobacteriaceae Take Part in Marine Biocorrosion of Carbon Steel.* J. Applied Microbiol, 102: 161-168.

Biro Klasifikasi Indonesia (BKI). 2004. *Regulations for the Corrosion Protection and Coating Systems, edisi 2004*. Jakarta: Biro Klasifikasi Indonesia

Bundjali, B. 2005. *Tinjauan Termodinamika dan Kinetika Korosi serta Teknik-Teknik Pengukuran Laju Korosi*. Bandung: ITB.

Davis, Troxell, dan Hauck. 1998. *The Testing of Engineering Materials, edisi 4*. Penerbit Mc Graw Hill. New York.

Fontana, Mars G, 1986, *Corrosion Engineering Third Edition*, New York: Mc Graw- Hill

Hudson, R. 1982. *Surface Preparation for Coating*. The National Physical Labotary

Khorasanizadeh, S. 2010. *The Effects of Shot and Grit Blasting Process Parameters on Steel Pipes Coating Adhesion*. International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:4 ; No:6.

Nugroho, C. T. 2016. *Analisa Pengaruh Material Abrasif pada Blasting Terhadap Daya Lekat Cat dan Ketahanan Korosi di Lingkungan Air Laut*. Tugas Akhir Mahasiswa Teknik Kelautan, FTK, ITS.

Phillip, Schweitzer A. 1987. *Corrosion*. United State of America: Marcell Decker Inc.

Saito, S., Surdia T. 2000. *Pengetahuan Bahan Teknik*. Jakarta: Pradnya Paramitha.

Sidiq, M. F. 2013. *Analisa Korosi dan Pengendaliannya*. Journal Foundry Vol. 3 No. 1. ISSN, 2087-2259.

SSPC: The Society for Protective *Coating*s. 2002. *SSPC-VIS 1 - Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning*. The Society for Protective *Coating*s

Supomo, Heri. 2003. *Buku Ajar Korosi*, Jurusan Teknik Perkapalan FTK – ITS, Surabaya.

Susetyo, Priyo. 2011. Analisa Teknis dan Ekonomis Penggunan Pasir Volkano sebagai Alternatif Material Abrasif di Galangan. Tugas Akhir Mahasiswa Teknik Perkapalan, FTK, ITS.

Umoren, S. A., Obot, I. B., Ebenso, E. E., & Obi-Egbedi, N. O. 2008. *Synergistic Inhibit ion between Naturally Occurring Exudate Gum and Halide Ions on the Corrosion of Mild Steel in Acidic Medium*. Int. J. Electrochem. Sci, 1029-1043.

Wiryosumarto, Harsono. 2000. *Teknologi Pengelasan Logam*. PT. Pradnya Paramita, Jakarta

# LAMPIRAN I

# DOKUMENTASI PENGUJIAN

**Gambar 1.** Pelat baja ASTM A36 (bawah) dan A53 (atas)


**Gambar 2.** Pelat baja setelah di-*blasting*

**Gambar 3.** Proses pencampuran cat *epoxy* dengan *hardener*

**Gambar 4.** Proses penyemprotan cat *epoxy* ke permukaan pelat pasca-*blasting*

**Gambar 5.** Proses penempelan *dolly* untuk uji daya lekat

# LAMPIRAN II

## *PRODUCT DATA*

## *Hempel Hempadur Multi-Strength GF 35870*

# Product Data
## HEMPADUR MULTI-STRENGTH GF 35870

### 35870 : BASE 35879 : CURING AGENT 98870

**Description:** HEMPADUR MULTI-STRENGTH GF 35870 is an amine-adduct cured epoxy coating - the product is reinforced with Glassflakes. It is a hard, impact and abrasion resistant coating with good resistance to sea water and splashes from petrol and related products. Suitable for early water exposure and will continue to cure under water.

**Recommended use:** As a self-primed, high build coating primarily for areas subject to abrasion and/or to a highly corrosive environment. E.g. splash zones, jetty pilings and working decks.

**Service temperature:** Maximum, dry exposure only: 140°C/284°F
In water (no temperature gradient): 60°C/140°F
Maximum peak temperature in water is 80°C/176°F.

**Certificates/Approvals:** Recognized Abrasion Resistant Ice Coating by Lloyds Register.
Tested for non-contamination of grain cargo at the Newcastle Occupational Health & Hygiene, Great Britain.

**Availability:** Part of Group Assortment. Local availability subject to confirmation.

**PHYSICAL CONSTANTS:**

| | |
|---|---|
| Shade nos/Colours: | 19990 / Black. |
| Finish: | Glossy |
| Volume solids, %: | 87 ± 1 |
| Theoretical spreading rate: | 2.5 $m^2$/l [100.2 sq.ft./US gallon] - 350 micron/14 mils |
| Flash point: | 35 °C [95 °F] |
| Specific gravity: | 1.3 kg/litre [11.1 lbs/US gallon] |
| Surface-dry: | 4 approx. hour(s) 20°C/68°F |
| Dry to touch: | 6 approx. hour(s) 20°C/68°F |
| Fully cured: | 7 day(s) 20°C/68°F |
| VOC content: | 188 g/l [1.6 lbs/US gallon] |
| Shelf life: | 2 years for BASE and 3 years (25°C/77°F) for CURING AGENT from time of production. |

*The physical constants stated are nominal data according to the HEMPEL Group's approved formulas.*

**APPLICATION DETAILS:**

| | |
|---|---|
| **Version, mixed product:** | **35870** |
| Mixing ratio: | BASE 35879 : CURING AGENT 98870<br>3 : 1 by volume |
| Application method: | Airless spray |
| Thinner (max.vol.): | 08450 (5%) |
| Pot life: | 1 hour(s) 20°C/68°F |
| Nozzle orifice: | 0.023 - 0.027 " Reversible |
| Nozzle pressure: | 250 bar [3625 psi]<br>(Airless spray data are indicative and subject to adjustment) |
| Cleaning of tools: | HEMPEL'S TOOL CLEANER 99610 |
| Indicated film thickness, dry: | 350 micron [14 mils] |
| Indicated film thickness, wet: | 400 micron [16 mils] |
| Overcoat interval, min: | see REMARKS overleaf |
| Overcoat interval, max: | see REMARKS overleaf |

**Safety:** Handle with care. Before and during use, observe all safety labels on packaging and paint containers, consult HEMPEL Safety Data Sheets and follow all local or national safety regulations.

# Product Data
## HEMPADUR MULTI-STRENGTH GF 35870

SURFACE PREPARATION:

**New steel:** Remove oil and grease etc. thoroughly with suitable detergent. Remove salts and other contaminants by high pressure fresh water cleaning. Abrasive blasting to near white metal Sa 2½ with a surface profile corresponding to Rugotest No. 3, BN10, Keane-Tator Comparator 3.0 G/S, or ISO Comparator Rough Medium (G). After blasting, clean the surface carefully from abrasives and dust.
**Maintenance:** Remove oil and grease etc. thoroughly with suitable detergent. Remove salts and other contaminants by high pressure fresh water cleaning. Remove all rust and loose material by wet or dry abrasive blasting or power tool cleaning. Feather edges to sound and intact areas. After wet abrasive blasting hose down the surface with fresh water and allow drying.
Touch up bare spots to full film thickness when the surface has become visually dry.

APPLICATION CONDITIONS:

Apply only on a dry and clean surface with a temperature above the dew point to avoid condensation. May be applied and will cure at temperatures down to 5°C/41°F. The temperature of the paint itself should be above: 15°C/59°F. The best result is obtained at: 20-30°C/68-86°F. In confined spaces provide adequate ventilation during application and drying.

PRECEDING COAT:

None. If a blast primer is required, use: HEMPADUR 15590.

SUBSEQUENT COAT:

None, or as per specification.

REMARKS:

Certificates/Approvals:

The recognition as Abrasion Resistant Ice Coating by Lloyds Register applies to the product as well as production site – at present the certificate is valid only for paint material produced at the following Hempel factories: Hempel Paints Poland, Buk.

Colours/Colour stability:

Light shades will have a tendency to yellow when exposed to sunshine and darken when exposed to heat.

Weathering/service temperatures:

The natural tendency of epoxy coatings to chalk in outdoor exposure and to become more sensitive to mechanical damage and chemical exposure at elevated temperatures is also reflected in this product.

Application(s):

The product may be immersed after 4 hours of initial curing at 20°C/68°F. Curing will proceed under water. Early immersion may result in some discolouration. This does not affect the protective properties of the product.

Application equipment:

Standard airless heavy-duty spray equipment:
Recommended pump ratio: minimum 45:1
Pump output: 12 litres/minute (theoretical)
Spray hoses: max 15 metres/50 feet, 3/8" internal diameter, max 3 metres/10 feet, 1/4" internal diameter
If longer spray hoses are necessary it is possible to add up to : 50 meters / 150 feet.
The high output capacity of the pump must be obtained. The ratio must be raised to:60:1.
Bigger spray nozzles will also call for increased pump size. A reversible nozzle is recommended.
Surge tank filter and tip filter should be removed.

Film thicknesses/thinning:

May be specified in another film thickness than indicated depending on purpose and area of use. This will alter spreading rate and may influence drying time and overcoating interval. Normal range dry is: 350-500 micron/14-20 mils

Overcoating:

Overcoating intervals related to later conditions of exposure: If the maximum overcoating interval is exceeded, roughening of the surface is necessary to ensure intercoat adhesion.
Before overcoating after exposure in contaminated environment, clean the surface thoroughly with high pressure fresh water hosing and allow drying.

A specification supersedes any guideline overcoat intervals indicated in the table.

| Environment | Atmospheric, medium | | | | | |
|---|---|---|---|---|---|---|
| Surface temperature: | 10°C (50°F) | | 20°C (68°F) | | 30°C (86°F) | |
| | Min | Max | Min | Max | Min | Max |
| HEMPADUR | 15 h | 150 d | 6 h | 60 d | 3 h | 30 d |
| HEMPATHANE | 10 h | 25 d | 4 h | 10 d | 2 h | 5 d |
| Environment | Immersion | | | | | |
| HEMPADUR | 40 h | 75 d | 16 h | 30 d | 8 h | 15 d |

NR = Not Recommended, Ext. = Extended, m = minute(s), h = hour(s), d = day(s)

Note:

**HEMPADUR MULTI-STRENGTH GF 35870 For professional use only.**

ISSUED BY:

HEMPEL A/S 3587019990

**This Product Data Sheet supersedes those previously issued.**
**For explanations, definitions and scope, see "Explanatory Notes" available on www.hempel.com. Data, specifications, directions and recommendations given in this data sheet represent only test results or experience obtained under controlled or specially defined circumstances. Their accuracy, completeness or appropriateness under the actual conditions of any intended use of the Products herein must be determined exclusively by the Buyer and/or User.**
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**Product data are subject to change without notice and become void five years from the date of issue.**

# LAMPIRAN III

## ASTM D4414

***Standard Practice for Measurement of Wet Film Thickness by Notch Gages***

Designation: D 4414 – 95 (Reapproved 2001)

# Standard Practice for Measurement of Wet Film Thickness by Notch Gages[1]

This standard is issued under the fixed designation D 4414; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice describes the use of thin rigid metal notched gages, also called step or comb gages, in the measurement of wet film thickness of organic coatings, such as paint, varnish, and lacquer.

1.2 Notched gage measurements are neither accurate nor sensitive, but they are useful in determining approximate wet film thickness of coatings on articles where size(s) and shape(s) prohibit the use of the more precise methods given in Methods D 1212.

1.3 This practice is divided into the following two procedures:

1.3.1 *Procedure A*—A square or rectangular rigid metal gage with notched sides is used to measure wet film thicknesses ranging from 3 to 2000 µm (0.5 to 80 mils 1). Such a gage is applicable to coatings on flat substrates and to coatings on articles of various sizes and complex shapes where it is possible to get the end tabs of the gage to rest in the same plane on the substrate.

1.3.2 *Procedure B*—A circular thin rigid metal notched gage is used to measure wet film thicknesses ranging from 25 to 2500 µm (1 to 100 mils ). Such a gage is applicable to coatings on flat substrates and to coatings on objects of various sizes and complex shapes.

1.4 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 1212 Test Methods for Measurement of Wet Film Thickness of Organic Coatings[2]

## 3. Summary of Practice

3.1 The material is applied to the articles to be coated and the wet film thickness measured with a notched gage.

3.2 *Procedure A*—A square or rectangular thin rigid metal gage with notched sides, having tabs of varying lengths, is pushed perpendicularly into the film. After removal from the film, the gage is examined and the film thickness is determined to lie between the clearance of the shortest tab wet by the film and the clearance of the next shorter tab not wetted by the film.

3.3 *Procedure B*—A circular thin rigid metal gage having spaced notches of varying depths around its periphery is rolled perpendicularly across the film. After removal from the film, the gage is examined and the film thickness is determined as being between the clearance of the deepest face wetted and the clearance of the next deepest notch face not wetted by the film.

## 4. Significance and Use

4.1 Wet film thickness measurements of coatings applied on articles can be very helpful in controlling the thickness of the final dry coating, although in some specifications the wet film thickness is specified. Most protective and high performance coatings are applied to meet a requirement or specification for dry film thickness for each coat or for the completed coating system, or for both.

4.2 There is a direct relationship between dry film thickness and wet film thickness. The wet film/dry film ratio is determined by the volume of volatiles in the coating as applied, including permitted thinning. With some flat coatings the dry film thickness is higher than that calculated from the wet film thickness. Consequently, the results from the notch gage are not to be used to verify the nonvolatile content of a coating.

4.3 Measurement of wet film thickness at the time of application is most appropriate as it permits correction and adjustment of the film by the applicator at the time of application. Correction of the film after it has dried or chemically cured requires costly extra labor time, may lead to

[1] This practice is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

Current edition approved Nov. 10, 1995. Published January 1996. Originally published as D 4414 – 84. Last previous edition D 4414 – 84 (1990)$^{\epsilon 1}$.

[2] *Annual Book of ASTM Standards*, Vol 06.01.

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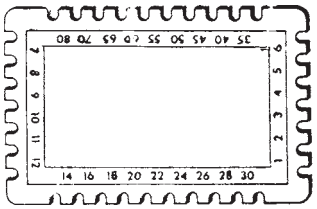

FIG. 1 Rectangular Notched Gage

contamination of the film, and may introduce problems of adhesion and integrity of the coating system.

4.4 The procedures using notched gages do not provide as accurate or sensitive measurements of wet film thickness as do the Interchemical and Pfund gages described in Methods D 1212. Notch gages may, however, be used on nonuniform surfaces, like concrete block, that are too rough to use the Interchemical and Pfund gages. Also notched gages can be very useful in the shop and field for determining the approximate thickness of wet films over commercial articles where size(s) and shape(s) are not suitable for measurements by other types of gages. Examples of such items are ellipses, thin edges, and corners.

4.5 An operator experienced in the use of a notched gage can monitor the coating application well enough to ensure the minimum required film thickness will be obtained.

4.6 Application losses, such as overspray, loss on transfer, and coating residue in application equipment, are a significant unmeasurable part of the coating used on a job and are not accounted for by measurement of wet film thickness.

## 5. Report

5.1 Report the following information:

5.1.1 The mean and range of the readings taken and the number of readings.

5.1.2 The smallest graduation of the gage used.

## 6. Precision and Bias

6.1 The precision and bias of Procedure A or B for measuring wet film thickness with notch gages are very dependent on methods of film application, time that the measurement is taken after film application, mechanical condition of the notch gages, and the step range of the gages.

6.2 Generally, the agreement between notch gages is good because they are insensitive to small differences in film thickness, that is the step intervals of the gages are relatively large.

## PROCEDURE A

## 7. Apparatus

7.1 *Notched Gage*, square or rectangular, thin rigid metal plate, with notched sides (see Fig. 1), made from steel or aluminum[3] (Note 1). Nonmetallic gages shall not be used.

NOTE 1—Aluminum or aluminum alloy gages are more easily distorted and may exhibit greater wear than steel gages. Gages made of plastic or deformable metal are not suitable.

7.1.1 Each notched side shall consist of a series of tabs (between notches) varying in length and located in a line between two end tabs equal in length and longest in the row.

7.1.2 As an example, the tabs on one row of a gage may differ in length as follows:

By 13 µm ( 0.5 mil) between 0 to 150 µm (0 and 6 mils),
By 25 µm (1 mil) between 150 to 250 µm (6 and 10 mils),
By 50 µm (2 mils) between 250 to 750 µm (10 and 30 mils), and
By 125 µm(5 mils) over 750 µm (30 mils).

## 8. Procedure

8.1 Apply the coating material to a rigid substrate and test with the gage immediately. The gage must be used immediately following application of the coating. Some coatings lose solvents quickly and spray application increases the speed. The resulting rapid reduction in wet film thickness can cause misleading readings.

8.2 Locate an area sufficiently large to permit both end tabs of the gage to rest on the substrate in the same plane.

8.3 Push the gage perpendicularly into the wet film so that the two end tabs rest firmly on the substrate at the same time.

8.4 Or, set one end tab firmly on the substrate and lower the gage until the other end tab is firmly in contact with the substrate.

8.5 Remove the gage from the film and examine the tabs. The film thickness is determined as being between the clearance of the shortest tab wettedd and the clearance of the next shorter tab not wetted by the film.

8.6 Clean the gage immediately after each reading by wiping it on a dry or solvent-dampened cloth so that subsequent readings are not affected. Do not clean with metal scrapers.

8.7 Repeat the procedure in 8.2-8.5 for at least three locations on the film. The number of readings required to obtain a good estimate of the film thickness varies with the shape and size of the article being coated, with the operator's experience, and whether one or more of the following problems are encountered:

8.7.1 Some coatings may not wet (leave residue on) some metal gages. However, the film itself may show where contact was made. When reading the gage, look at both the gage and the film itself for verification of the reading.

8.7.2 The gage may slip on the surface. Ignore such readings.

8.7.3 The surface may be coarse and false readings produced. The spot where the gage is used must be as uniform as possible and questionable readings ignored.

8.8 Determine the mean and range of the readings.

## 9. Report

9.1 Report the mean and range of the readings.

[3] These gages are commercially available from various coating equipment and instrument suppliers.

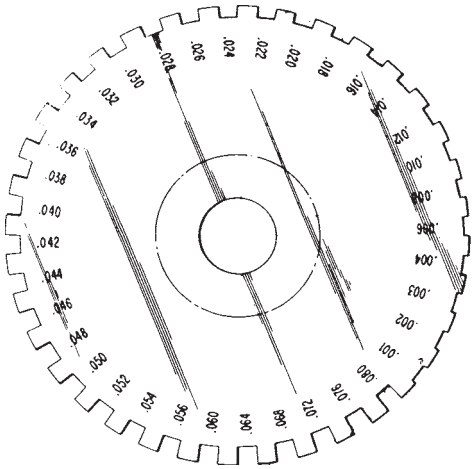

FIG. 2 Circular Notched Gage

## PROCEDURE B

### 10. Apparatus

10.1 *Circular Notched Gage*,[4] thin metal disk, with calibrated notches of various depths spaced around its periphery (see Fig. 2). Each notch has a recessed flat face. A hole is in the center of the disk.

10.2 Examples of the scale increments and ranges provided by the notches are:

10.2.1 25–µm increments between 25 µm to 100 µm (1 to 4 mils),

10.2.2 50–µm increments between 150 µm to 1500 µm (6 and 60 mils), and

10.2.3 100–µm increments between 1500 µm to 2000 µm(60 and 80 mils ).

### 11. Procedure

11.1 Select a gage that has a segment with a thickness scale appropriate for the expected range of wet-film thickness.

11.2 Locate areas on the rigid substrate sufficiently large to permit the gage to roll for at least 1½ in. (40 mm).

11.3 Apply the liquid coating to the substrate and immediately place the selected segment perpendicularly on the wet film and in firm contact with the substrate. Roll the gage across the film, holding the disk with a thumb and index finger in the center hole.

11.4 Remove the gage from the film and inspect the notch faces. The wet-film thickness is determined as being between the clearance of the deepest notch face wetted and the clearance of the next deeper notch face not wetted by the film.

11.5 Clean the gage immediately after each reading by wiping on a dry or solvent-dampened cloth so that subsequent readings are not affected. Do not clean with metal scrapers.

11.6 Repeat the procedure from 11.1-11.5 as described in 8.7.

11.7 Determine the mean and range of the readings.

### 12. Report

12.1 Report the mean and range of the readings.

### 13. Keywords

13.1 circular notched gage; rectangular notched gage

[4] The “Hotcake” Wet Film Thickness Gage is covered by a patent held by Paul N. Gardner, Sr., 316 N.E. First Street, Pompano Beach, FL 33060. Interested parties are invited to submit information regarding the identification of acceptable alternatives to this patented item to the Committee on Standards, ASTM Headquarters, 100 Barr Harbor Drive., West Conshohocken, PA 19428. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

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# LAMPIRAN IV

## ASTM D4138

***Standard Test Methods for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means***

Designation: D 4138 – 94 (Reapproved 2001)ε1

# Standard Test Methods for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means[1]

This standard is issued under the fixed designation D 4138; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε[1] NOTE—Editorial changes made throughout in June 2001.

## 1. Scope

1.1 These test methods cover the measurement of dry film thickness of coating films by microscopic observation of precision angular cuts in the coating film. Use of these methods may require repair of the coating film.

1.2 Three test methods are provided for measuring dry film thickness of protective coating system:

1.2.1 *Test Method A*—Using groove cutting instruments.

1.2.2 *Test Method B*—Using grinding instruments.

1.2.3 *Test Method C*—Using drill bit instruments.

1.3 The substrate should be sufficiently rigid to prevent deformation of the coating during the cutting process. The surface may be flat or moderately curved (pipes as small as 1 in. (25 mm) in diameter may be measured in the axial direction).

1.4 The range of thickness measurement is 0 to 50 mils (0 to 1.3 mm).

1.5 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels[2]

D 1005 Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers[2]

D 1186 Test Methods for Nondestructive Measurements of Dry-Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base[2]

D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base[2]

## 3. Summary of Test Methods

3.1 The three methods are based on measurement of dry film thickness by observation of angular cuts in the coating through a microscope having a built-in reticle with a scale. Each method employs different instruments to make the cut in the coating.

3.2 *Test Method A*—Uses a carbide tipped wedge to cut a groove in the coating. The groove is cut at a precise angle to the surface. Three wedge angles are available.

3.3 *Test Method B*—Uses a high speed rotary grinding disk or drum type bit to cut partial cylindrical cavities in the coating. Axes of the cavities can be oriented at three angles of inclination to the surface.

3.4 *Test Method C*—Uses a specific angle tip drill bit to cut a conical cavity in the coating.

## 4. Significance and Use

4.1 The use of these test methods is not necessarily limited by the type of substrate material as are nondestructive magnetic-type means.

4.2 Individual coats or the overall thickness of a coating system can be measured by these methods.

## 5. Test Method A—Groove Cutting Instruments

5.1 *Apparatus*

[1] These test methods are under the jurisdiction of ASTM Committee D33 on Protective Coating and Lining Work for Power Generation Facilities and is the direct responsibility of Subcommittee D33.04 on Quality Systems and Inspection.

Current edition approved Jan. 15, 1994. Published March 1994. Originally published as D 4138 – 82. Last previous edition D 4138 – 88.

[2] *Annual Book of ASTM Standards*, Vol 06.01.

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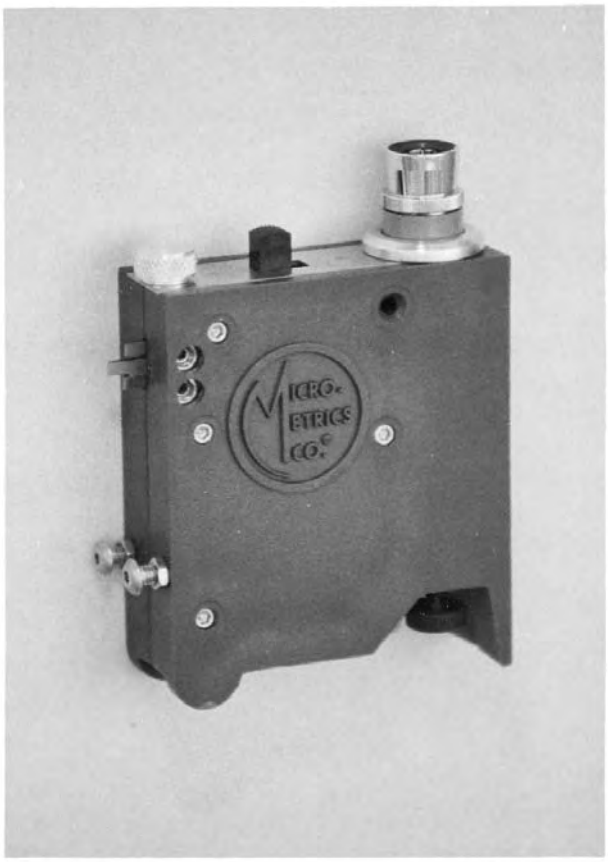


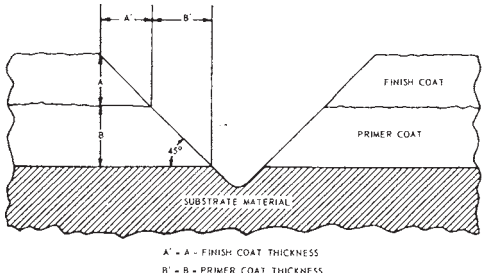

**FIG. 1 Tooke Inspection Gage[3]**

5.1.1 *Scribe Cutter and an Illuminated Microscope, with Measuring Reticle.* The scribe cutter and illuminated microscope may be combined as a single instrument (see Fig. 1).[3] The instrument calibration shall be performed by taking measurements on applied films of known thickness (see Test Method D 1005).

5.1.2 *Tungsten Carbide Cutting Tips* shall be designed to provide a very smooth incision in the paint film at a precise angle to the surface (see Fig. 2 ). Separate tip designs (angles) shall provide cuts of known slopes such as 1 to 1, 1 to 2, and 1 to 10. These tips shall be nominally designated 1×, 2×, and 10× to indicate the ratio of the lateral measurement to vertical depth. The lateral measurement is represented by the reticle markings and the vertical depth is represented by the coating film thickness. Metal guide studs on the gage body shall, together with the cutting tip, form a firm base to ensure that the tip aligns vertically with the painted surface for a precisely aligned incision.

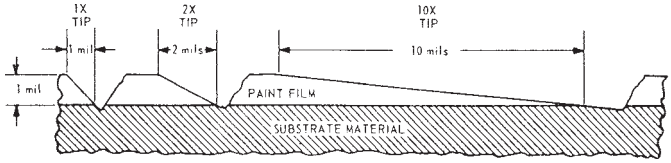
5.1.3 *Illuminated, 50-Power Microscope* shall contain a reticle scaled from 0 to 100 divisions (see Fig. 3). The total viewing field of the microscope shall be approximately 125 mils (3.18 mm).

[3] The sole source of supply of the Tooke gage known to the committee at this time is MicroMetrics, P.O. Box 13804, Atlanta, GA 30324. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.




**(A)**

**FIG. 2 Geometry of Thickness Measurement**




**(B)**

**FIG. 2 Grooves Made by 1×, 2×, and 10× Cutting Tips** *(continued)*

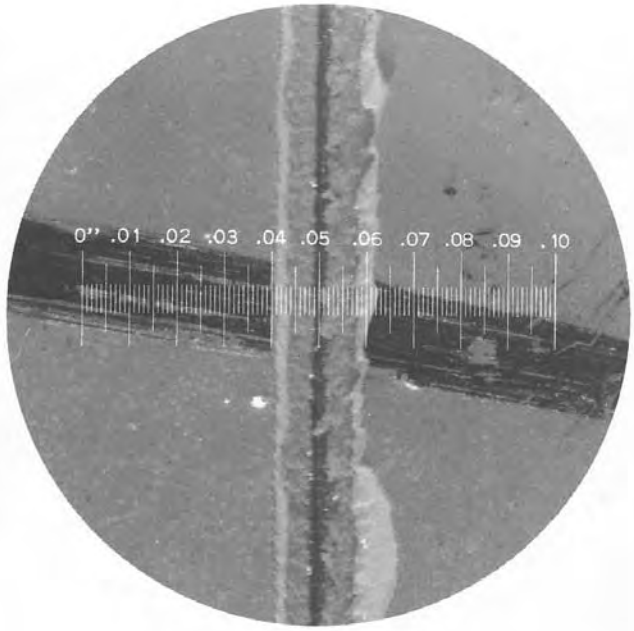



**FIG. 3 Typical View Through Microscope of Tooke Inspection Gage Showing Reticle**

NOTE 1—A photomicrographic adapter is available with some microscopic instruments that allows photographs to be taken through the view finder.

5.2 *Test Specimens*

5.2.1 If multiple coats of paint are to be measured, successive contiguous coats should be of contrasting colors to aid sharp discrimination of interfaces.

5.2.2 Generally, test specimens shall be prepared (as test panels) or chosen (as sites on a structure) to be representative of localized coating thickness and variability.

5.2.3 For test panels, if measurement repeatability is desired for a particular paint system, care shall be taken in panel preparation. Coating shall be uniformly applied in accordance with Test Method D 823. Panels shall be placed in a horizontal position during drying. Uniform application thickness shall be verified by another measurement method such as Test Methods D 1005, D 1186, or D 1400.

5.3 *Procedure*

5.3.1 Select a test panel or choose a site for the thickness measurement.

5.3.2 Using an appropriate surface marker of contrasting color, mark a line on the surface approximately 2-in. long (51-mm) where the thickness measurement will be made.

5.3.3 Select a cutting tip based on estimated film thickness as follows:

| Tip | Thickness Range, mils (μm) | Conversion Factor |
|---|---|---|
| 1× | 20 to 50 (500 to 1250) | 1.0 |
| 2× | 2 to 20 (50 to 500) | 0.5 |
| 10× | 0 to 3 (0 to 75) | 0.1 |

If thickness is unknown, make a trial determination with the 2× tip.

5.3.4 To cut a groove, grasp the gage with the studs and cutting tip firmly forming a tripod on the painted surface. Place the gage at right angles to and about 2 in. (51 mm) perpendicularly from a marked line.

5.3.5 Draw the gage across the paint film toward the body, with guide studs leading the cutting tip, and increase pressure on the cutting tip until it barely cuts into the substrate before it crosses the marked line.

5.3.6 Take readings at the intersection of the marked line and incision. Read by measuring on the reticle the distance from the substrate/coating demarcation up the longer machined slope of the incision to the upper cut edge of each respective coating layer of the coating system. Make sure that the smooth cut face of the groove is measured. (The machined upper edge of the cutting tip usually leaves a less jagged cut). If multiple coats are observed, individual thicknesses of each coat may be read. The actual coating thickness is derived by multiplying the reticle reading by the conversion factor for the respective cutting tip.

## 6. Test Method B—Grinding Instruments

6.1 *Apparatus*

6.1.1 *Rotary Tool*[4]—A cordless high speed (5000 to 10 000 r/m) rotary grinder.

6.1.2 *Grinding Bit*—Tungsten carbide cylindrical-shaped grinding bit placed in a chuck of a microgroover for grinding through the coating system.

6.1.3 *Positioning Block*—The positioning block provides two specific angles with the coated surface for microgroover grinding through the coating system. The third angle is accomplished without using the positioning block.

6.1.4 *Measuring Microscope*—A 50-power illuminated microscope used in Test Method A is also used in Test Method B (see 5.1.3).

6.2 *Test Specimens*

6.2.1 See requirements outlined in 5.2.

6.3 *Procedure*

6.3.1 Select a test panel or choose a site for thickness measurement.

6.3.2 Using an appropriate surface marker of contrasting color, mark a line on the surface approximately ¼-in. (6.2-mm) wide by approximately 1-in. (25.4-mm) long where the thickness measurement will be made.

6.3.3 Select a grinding position based on estimated coating system thickness as follows:

| Position | Coating System Thickness, mils (μm) | Conversion Factor |
|---|---|---|
| 1× | 20 to 50 (500 to 1250) | 1.0 |
| 2× | 2 to 20 (50 to 500) | 0.5 |
| 4× | 0 to 3 (0 to 75) | 0.25 |

If thickness is unknown, make a trial determination in 2× position.

6.3.4 Install the tungsten carbide grinding tip so that it extends 1¼ in. (31.75 mm) from the chuck mouth.

6.3.5 The cut is made by grinding a groove through the coating system down to the substrate.

NOTE 2—Take care to hold the instrument at the predetermined angle with sufficient firmness to prevent sideways movement, as shown in Fig. 4.

6.3.6 Grinding slopes or positions of 1×, 2×, and 4× are accomplished by using the "position block" or supports as follows (see Fig. 5):

1×: 0.97 in. (24.6 mm) high (block resting on narrow face)
2×: 0.41 in. (10.4 mm) high (block resting on wide face)
4×: 0.0 in. (0.0 mm) (block not used)

6.3.7 Ground area will appear as partial cylindrical cavity, with the cavity wall angling gradually upward from the substrate to the coating system's exterior surface.

6.3.8 Thickness of each coating system layer of any combination of layers may be determined using an illuminated microscope as indicated in paragraph 5.1.3. Fig. 6. depicts the groove that results from grinding through a coating system. Note that the sketch depicts successive coats and the reticle graduations associated with each. The sum of the reticle graduations shall be multiplied by the appropriate conversion factor for the instrument angle position used.

## 7. Test Method C—Drilling Instruments

7.1 *Apparatus*

[4] The sole source of supply of the grinding bit and positioning block components of the Microgroover kit known to the committee at this time is MicroMetrics, P.O. Box 13804, Atlanta, GA 30324. As is evident in Fig. 4, a suitable rotary tool is the "Minimite" manufactured by Dremel, 4915 21st St., Racine, WI. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

FIG. 4 Holding Microgroover[4] for Grinding

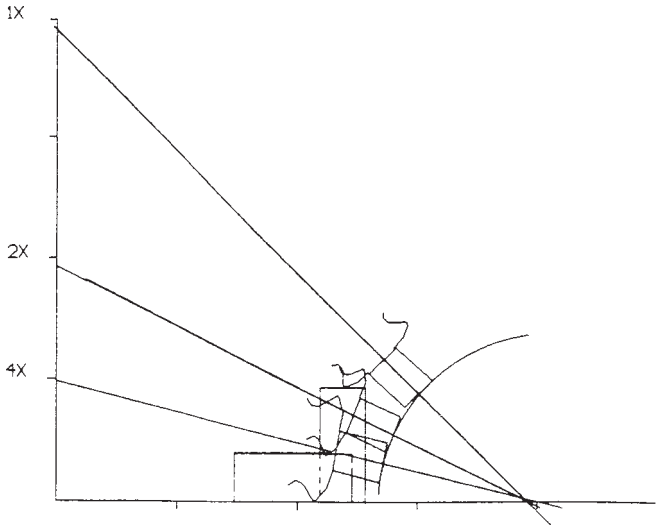
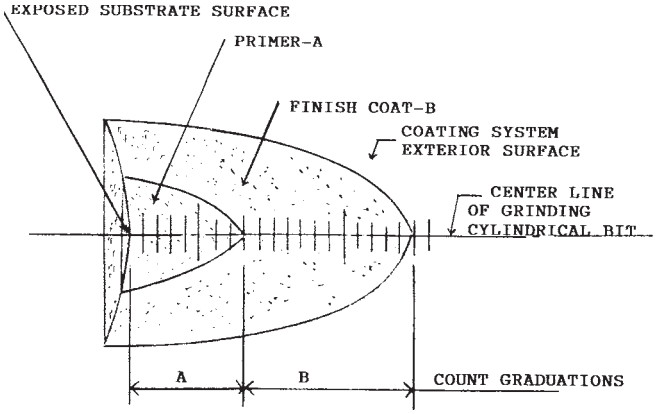



FIG. 5 Microgroover Block—Positions for Various Cutting Angles (Slopes)




NOTE 1—The coating thickness is determined using the graduations along the long axis of the cut represented by the A and B dimensions in this drawing.

FIG. 6 Typical View Through Microscope of Tooke Inspection Gage for Microgroover

7.1.1 *Cutter/Drill Body*—An implement to hold the drill bit in place over the coating system surface (see Fig. 7).[5]

7.1.2 *Handwheels*—Light and heavy hand wheels for holding the cutter/drill in place and turning.

7.1.3 *Cutter/Drill*—Cutter/drill bit to penetrate through the coating system down to the substrate.

7.1.4 *Microscope*—A 50-power microscope with scaled divisions showing through reticle.

7.2 *Test Specimens*

7.2.1 See requirements outlined in 5.2.

7.3 *Procedure*

7.3.1 Select a test panel or choose a site for thickness measurement.

7.3.2 Using an appropriate surface marker of contrasting color, mark a surface area ¼ by ¼ in. (6.2 mm) where the thickness measurement will be made.

7.3.3 Select the appropriate handwheel. Use the heavy wheel on hard or thick coatings above 10 mils (250 µm) and light wheel for soft or thin coatings below 10 mils.

7.3.4 Insert the cutter in the handwheel selected. Tighten the recess socket-head screw.

7.3.5 Place the drill body on the surface to be measured with the hole directly above the measurement area. Fit the cutter into the drill hole.

7.3.6 Rotate the handwheel in a clockwise direction, using pressure as necessary (for soft coatings rotate with finger in recess) until the cutter has penetrated the coating and marked the substrate.

7.3.7 Remove the cutter assembly and the drill body. View the cut hole with the microscope, focusing on the side of the hole.

7.3.8 Note the number of reticle divisions between the coating surface and the substrate or the individual layers of paint as shown in Fig. 8.

[5] The sole source of supply of the Salberg thickness drill known to the committee at this time is Elcometer Inc., 1893 Rochester Industrial Drive, Rochester Hill, MI 48309. If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.


**FIG. 7 Saberg[5] Drill With Microscope**

7.3.9 To calculate the coating thickness: for mils—multiply gradations by 0.79, and for microns—multiply gradations by 20.0.

## 8. Report

8.1 Report the following information:

8.1.1 Results of a thickness determination, and

8.1.2 If more than one measurement is made and specific results for each location are not needed, report the minimum, the maximum, and the average thickness.

## 9. Precision

9.1 Individual observations of a uniform coating on a smooth substrate have been determined to be within ±10 % (the percentage error increases as film thickness decreases).

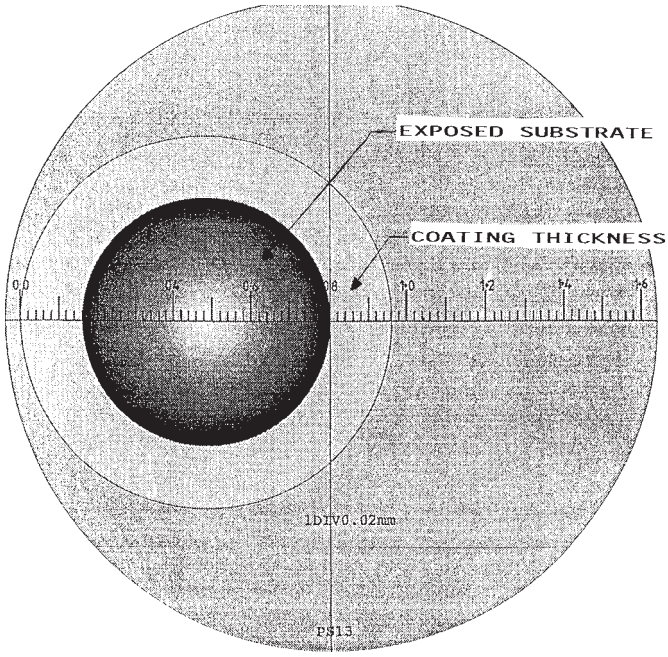



**FIG. 8 Typical View Through Microscope Used with Saberg Drill**

9.2 Field-applied coatings are characteristically subject to short-range thickness variability resulting from rough substrates and normal variations in application. The magnitude of this variability will be reflected by the range or standard deviation of thickness determinations.

## 10. Keywords

10.1 destructive means; dry film thickness; individual coats; measurement; microscopic observation; overall thickness; reticle; scale

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# LAMPIRAN V

# ASTM D4541-02

## *Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers*

Designation: D 4541 – 09

# Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers[1]

This standard is issued under the fixed designation D 4541; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope*

1.1 This test method covers a procedure for evaluating the pull-off strength (commonly referred to as adhesion) of a coating system from metal substrates. Pull-off strength of coatings from concrete is described in Test Method D 7234. The test determines either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass/fail). Failure will occur along the weakest plane within the system comprised of the test fixture, adhesive, coating system, and substrate, and will be exposed by the fracture surface. This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scratch or knife adhesion, and results may not be comparable.

NOTE 1—The procedure in this standard was developed for metal substrates, but may be appropriate for other rigid substrates such as plastic and wood. Factors such as loading rate and flexibility of the substrate must be addressed by the user/specifier.

1.2 Pull-off strength measurements depend upon both material and instrumental parameters. Results obtained by each test method may give different results. Results should only be assessed for each test method and not be compared with other instruments. There are five instrument types, identified as Test Methods B-F. It is imperative to identify the test method used when reporting results.

NOTE 2—Method A, which appeared in previous versions of this standard, has been eliminated as its main use is for testing on concrete substrates (see Test Method D 7234).

1.3 This test method uses a class of apparatus known as portable pull-off adhesion testers.[2] They are capable of applying a concentric load and counter load to a single surface so that coatings can be tested even though only one side is accessible. Measurements are limited by the strength of adhesion bonds between the loading fixture and the specimen surface or the cohesive strengths of the adhesive, coating layers, and substrate.

1.4 This test can be destructive and spot repairs may be necessary.

1.5 The values stated in MPa (inch-pound) units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[3]

D 2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding

D 3933 Guide for Preparation of Aluminum Surfaces for Structural Adhesives Bonding (Phosphoric Acid Anodizing)

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials[4]

D 7234 Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *ANSI Standard:*

N512 Protective Coatings (Paints) for the Nuclear Industry[5]

2.3 *ISO Standard:*

ISO 4624 Paints and Varnish—Pull-Off Test for Adhesion[5]

[1] This test method is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.46 on Industrial Protective Coatings.

Current edition approved Feb. 1, 2009. Published April 2009. Originally approved in 1993. Last previous edition approved in 2002 as D 4541 – 02.

[2] The term adhesion tester may be somewhat of a misnomer, but its adoption by two manufacturers and at least two patents indicates continued usage.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] Withdrawn.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

***A Summary of Changes section appears at the end of this standard.**

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## 3. Summary of Test Method

3.1 The general pull-off test is performed by securing a loading fixture (dolly, stud) normal (perpendicular) to the surface of the coating with an adhesive. After the adhesive is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually increased and monitored until either a plug of material is detached, or a specified value is reached. When a plug of material is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. The pull-off strength is computed based on the maximum indicated load, the instrument calibration data, and the original surface area stressed. Pull-off strength results obtained using different devices may be different because the results depend on instrumental parameters (see Appendix X1).

## 4. Significance and Use

4.1 The pull-off strength of a coating is an important performance property that has been used in specifications. This test method serves as a means for uniformly preparing and testing coated surfaces, and evaluating and reporting the results. This test method is applicable to any portable apparatus meeting the basic requirements for determining the pull-off strength of a coating.

4.2 Variations in results obtained using different devices or different substrates with the same coating are possible (see Section 10). Therefore, it is recommended that the type of apparatus and the substrate be mutually agreed upon between the interested parties.

4.3 The purchaser or specifier shall designate a specific test method, that is, B, C, D, E, or F when calling out this standard.

## 5. Apparatus

5.1 *Adhesion Tester*, commercially available, or comparable apparatus specific examples of which are listed in Annex A1-Annex A5.

5.1.1 *Loading Fixtures*, having a flat surface on one end that can be adhered to the coating and a means of attachment to the tester on the other end.

5.1.2 *Detaching Assembly* (adhesion tester), having a central grip for engaging the fixture.

5.1.3 *Base*, on the detaching assembly, or an annular bearing ring if needed for uniformly pressing against the coating surface around the fixture either directly, or by way of an intermediate bearing ring. A means of aligning the base is needed so that the resultant force is normal to the surface.

5.1.4 Means of moving the grip away from the base in as smooth and continuous a manner as possible so that a torsion free, co-axial (opposing pull of the grip and push of the base along the same axis) force results between them.

5.1.5 *Timer*, or means of limiting the loading rate to 1 MPa/s (150 psi/s) or less for a 20 mm loading fixture so that the test is completed in about 100 s or less. A timer is the minimum equipment when used by the operator along with the force indicator in 5.1.6.

5.1.6 *Force Indicator and Calibration Information*, for determining the actual force delivered to the loading fixture.

5.2 *Solvent*, or other means for cleaning the loading fixture surface. Finger prints, moisture, and oxides tend to be the primary contaminants.

5.3 *Fine Sandpaper*, or other means of cleaning the coating that will not alter its integrity by chemical or solvent attack. If any light sanding is anticipated, choose only a very fine grade abrasive (400 grit or finer) that will not introduce flaws or leave a residue.

5.4 *Adhesive*[6], for securing the fixture to the coating that does not affect the coating properties. Two component epoxies and acrylics have been found to be the most versatile.

5.5 *Magnetic or Mechanical Clamps*, if needed, for holding the fixture in place while the adhesive cures.

5.6 *Cotton Swabs*, or other means for removing excess adhesive and defining the adhered area. Any method for removing excess adhesive that damages the surface, such as scoring (see 6.7), must generally be avoided since induced surface flaws may cause premature failure of the coating.

5.7 *Circular Hole Cutter* (optional), to score through to the substrate around the loading fixture.

## 6. Test Preparation

6.1 The method for selecting the coating sites to be prepared for testing depends upon the objectives of the test and agreements between the contracting parties. There are, however, a few physical restrictions imposed by the general method and apparatus. The following requirements apply to all sites:

6.1.1 The selected test area must be a flat surface large enough to accommodate the specified number of replicate tests. The surface may have any orientation with reference to gravitational pull. Each test site must be separated by at least the distance needed to accommodate the detaching apparatus. The size of a test site is essentially that of the secured loading fixture. At least three replications are usually required in order to statistically characterize the test area.

6.1.2 The selected test areas must also have enough perpendicular and radial clearance to accommodate the apparatus, be flat enough to permit alignment, and be rigid enough to support the counter force. It should be noted that measurements close to an edge may not be representative of the coating as a whole.

6.2 Since the rigidity of the substrate affects pull-off strength results and is not a controllable test variable in field measurements, some knowledge of the substrate thickness and composition should be reported for subsequent analysis or laboratory comparisons. For example, steel substrate of less than 3.2 mm (⅛ in.) thickness usually reduces pull-off strength results compared to 6.4 mm (¼-in.) thick steel substrates.

6.3 Subject to the requirements of 6.1, select representative test areas and clean the surfaces in a manner that will not affect integrity of the coating or leave a residue. To reduce the risk of glue failures, the surface of the coating can be lightly abraded to promote adhesion of the adhesive to the surface. If the surface is abraded, care must be taken to prevent damage to the

[6] Scotch Weld 420, available from 3M, Adhesives, Coatings and Sealers Div., 3M Center, St. Paul, MN 55144, was used in the round robin.

coating or significant loss of coating thickness. Solvent clean the area to remove particulates after abrading. Select a solvent that does not compromise the integrity of the coating.

6.4 Clean the loading fixture surface as indicated by the apparatus manufacturer. Failures at the fixture-adhesive interface can often be avoided by treating the fixture surfaces in accordance with an appropriate ASTM standard practice for preparing metal surfaces for adhesive bonding.

NOTE 3—Guides D 2651 and D 3933 are typical of well-proven methods for improving adhesive bond strengths to metal surfaces.

6.5 Prepare the adhesive in accordance with the adhesive manufacturer's recommendations. Apply the adhesive to the fixture or the surface to be tested, or both, using a method recommended by the adhesive manufacturer. Be certain to apply the adhesive across the entire surface. Position fixture on the surface to be tested. Carefully remove the excess adhesive from around the fixture. (**Warning**—Movement, especially twisting, can cause tiny bubbles to coalesce into large holidays that constitute stress discontinuities during testing.)

NOTE 4—Adding about 1 percent of #5 glass beads to the adhesive assists in even alignment of the test fixture to the surface.

6.6 Based on the adhesive manufacturer's recommendations and the anticipated environmental conditions, allow enough time for the adhesive to set up and reach the recommended cure. During the adhesive set and early cure stage, a constant contact pressure should be maintained on the fixture. Magnetic or mechanical clamping systems work well, but systems relying on tack, such as masking tape, should be used with care to ensure that they do not relax with time and allow air to intrude between the fixture and the test area.

6.7 Scoring around the fixture violates the fundamental in situ test criterion that an unaltered coating be tested. If scoring around the test surface is employed, extreme care is required to prevent micro-cracking in the coating, since such cracks may cause reduced adhesion values. Scored samples constitute a different test, and this procedure should be clearly reported with the results. Scoring is only recommended for thicker-film coatings, that is, thicknesses greater than 500 µm (20 mils), reinforced coatings and elastomeric coatings. Scoring, if performed, shall be done in a manner that ensures the cut is made normal to the coating surface and in a manner that does not twist or torque the test area and minimizes heat generated and edge damage or microcracks to the coating and the substrate. For thick coatings it is recommended to cool the coating and substrate during the cutting process with water lubrication.

NOTE 5—A template made from plywood with a hole of the same size drilled through it has been found to be an effective method to limit sideways movement of the drill bit.

6.8 Note the approximate temperature and relative humidity during the time of test.

## 7. Test Procedure

7.1 Test Methods:

7.1.1 *Test Method A (discontinued).*

7.1.2 *Test Method B — Fixed Alignment Adhesion Tester Type II*:

7.1.2.1 Operate the instrument in accordance with Annex A1.

7.1.3 *Test Method C — Self-Alignment Adhesion Tester Type III*:

7.1.3.1 Operate the instrument in accordance with Annex A2.

7.1.4 *Test Method D — Self-Alignment Adhesion Tester Type IV*:

7.1.4.1 Operate the instrument in accordance with Annex A3.

7.1.5 *Test Method E — Self-Alignment Adhesion Tester Type V*:

7.1.5.1 Operate the instrument in accordance with Annex A4.

7.1.6 *Test Method F— Self-Alignment Adhesion Tester Type VI*:

7.1.6.1 Operate the instrument in accordance with Annex A5.

7.2 Select an adhesion-tester with a detaching assembly having a force calibration spanning the range of expected values along with its compatible loading fixture. Mid-range measurements are usually the best, but read the manufacturer's operating instructions before proceeding.

7.3 If a bearing ring or comparable device (5.1.3) is to be used, place it concentrically around the loading fixture on the coating surface. If shims are required when a bearing ring is employed, place them between the tester base and bearing ring rather than on the coating surface.

7.4 Carefully connect the central grip of the detaching assembly to the loading fixture without bumping, bending, or otherwise prestressing the sample and connect the detaching assembly to its control mechanism, if necessary. For nonhorizontal surfaces, support the detaching assembly so that its weight does not contribute to the force exerted in the test.

7.5 Align the device according to the manufacturer's instructions and set the force indicator to zero.

NOTE 6—Proper alignment is critical, see Appendix X1. If alignment is required, use the procedure recommended by the manufacturer of the adhesion tester and report the procedure used.

7.6 Increase the load to the fixture in as smooth and continuous a manner as possible, at a rate of 1 MPa/s (150 psi/s) or less for a 20 mm loading fixture so that the test is completed in about 100 s or less.

7.7 Record the force attained at failure or the maximum force applied.

7.8 If a plug of material is detached, label and store the fixture for qualification of the failed surface in accordance with 8.3.

7.9 Report any departures from the procedure such as possible misalignment, hesitations in the force application, etc.

## 8. Calculation and Interpretation of Results

8.1 If instructed by the manufacturer, use the instrument calibration factors to convert the indicated force for each test into the actual force applied.

8.2 Either use the calibration chart supplied by the manufacturer or compute the relative stress applied to each coating sample as follows:

$$X = 4F/\pi d^2 \quad (1)$$

where:

$X$ = greatest mean pull-off stress applied during a pass/fail test, or the pull-off strength achieved at failure. Both have units of MPa (psi),

$F$ = actual force applied to the test surface as determined in 8.1, and

$d$ = equivalent diameter of the original surface area stressed having units of inches (or millimetres). This is usually equal to the diameter of the loading fixture.

8.3 For all tests to failure, estimate the percent of adhesive and cohesive failures in accordance to their respective areas and location within the test system comprised of coating and adhesive layers. A convenient scheme that describes the total test system is outlined in 8.3.1 through 8.3.3. (See ISO 4624.)

NOTE 7—A laboratory tensile testing machine is used in ISO 4624.

8.3.1 Describe the specimen as substrate *A*, upon which successive coating layers *B*, *C*, *D*, etc., have been applied, including the adhesive, *Y*, that secures the fixture, *Z*, to the top coat.

8.3.2 Designate cohesive failures by the layers within which they occur as *A*, *B*, *C*, etc., and the percent of each.

8.3.3 Designate adhesive failures by the interfaces at which they occur as *A/B*, *B/C*, *C/D*, etc., and the percent of each.

8.4 A result that is very different from most of the results may be caused by a mistake in recording or calculating. If either of these is not the cause, then examine the experimental circumstances surrounding this run. If an irregular result can be attributed to an experimental cause, drop this result from the analysis. However, do not discard a result unless there are valid nonstatistical reasons for doing so or unless the result is a statistical outlier. Valid nonstatistical reasons for dropping results include alignment of the apparatus that is not normal to the surface, poor definition of the area stressed due to improper application of the adhesive, poorly defined glue lines and boundaries, holidays in the adhesive caused by voids or inclusions, improperly prepared surfaces, and sliding or twisting the fixture during the initial cure. Scratched or scored samples may contain stress concentrations leading to premature fractures. Dixon's test, as described in Practice D 3980, may be used to detect outliers.

8.5 Disregard any test where glue failure represents more than 50 % of the area. If a pass/fail criterium is being used and a glue failure occurs at a pull-off strength greater than the criterium, report the result as "pass with a pull-off strength > {value obtained}..."

8.6 Further information relative to the interpretation of the test results is given in Appendix X1.

## 9. Report

9.1 Report the following information:

9.1.1 Brief description of the general nature of the test, such as, field or laboratory testing, generic type of coating, etc.

9.1.2 Temperature and relative humidity and any other pertinent environmental conditions during the test period.

9.1.3 Description of the apparatus used, including: apparatus manufacturer and model number, loading fixture type and dimensions, and bearing ring type and dimensions.

9.1.4 Description of the test system, if possible, by the indexing scheme outlined in 8.3 including: product identity and generic type for each coat and any other information supplied, the substrate identity (thickness, type, orientation, etc.), and the adhesive used.

9.1.5 Test results.

9.1.5.1 Date, test location, testing agent.

9.1.5.2 For pass/fail tests, stress applied along with the result, for example, pass or fail and note the plane of any failure (see 8.3 and ANSI N512).

9.1.5.3 For tests to failure, report all values computed in 8.2 along with the nature and location of the failures as specified in 8.3, or, if only the average strength is required, report the average strength along with the statistics.

9.1.5.4 If corrections of the results have been made, or if certain values have been omitted such as the lowest or highest values or others, reasons for the adjustments and criteria used.

9.1.5.5 For any test where scoring was employed, indicate it by placing a footnote superscript beside each data point affected and a footnote to that effect at the bottom of each page on which such data appears. Note any other deviations from the procedure.

## 10. Precision and Bias [7,8]

10.1 The precision of this test method is based on an interlaboratory study of Test Method D 4541 conducted in 2006. Analysts from seven laboratories tested six different coatings applied to ¼ in. thick hot-rolled carbon steel plates using five different adhesion testers. Every "test result" represents an individual determination. In order to standardize and balance the data, any pull which exceeded the tester's upper limit with the available accessories at the time of testing was eliminated from the statistical analysis. Any pull in which there was 50 % or more glue failure was also eliminated from the statistical analysis. If four valid pulls were obtained from one operator for a given material, the fourth was eliminated and the first three valid replicate test results (from one operator) for each material were included in the statistical analysis. Practice E 691 was followed for the design and analysis of the data; the details are given in Research Report No. D01–1147.

NOTE 8—The pull-off strength of two of the coatings, identified during the round robin as Coating A and Coating F, exceeded the measurement limits of the testers with the accessories available at the time of testing, and were therefore eliminated from the statistical analysis.

10.1.1 *Repeatability*—Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the "*r*" value for that material; "*r*" is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

10.1.1.1 Repeatability limits are listed in Tables 1-5.

10.1.2 *Reproducibility*—Two test results shall be judged not equivalent if they differ by more than the "*R*" value for that

[7] Supporting data are available from ASTM International Headquarters. Request RR: D01-1094.

[8] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D01–1147.

**TABLE 1 Adhesion Testing Method B, Pull-Off Strength (*psi*)**

| Coating | Average | Repeatability Standard Deviation | Reproducibility Standard Deviation | Repeatability Limit | Reproducibility Limit |
|---|---|---|---|---|---|
| | $\bar{x}$ | sr | sR | r | R |
| B | 1195 | 278 | 330 | 777 | 925 |
| C | 549 | 109 | 117 | 305 | 326 |
| D | 1212 | 412 | 483 | 1155 | 1351 |
| E | 1385 | 192 | 276 | 537 | 774 |

| Coating | Average | Repeatability Limit | | Reproducibility Limit | |
|---|---|---|---|---|---|
| | $\bar{x}$ | r | % of average | R | % of average |
| B | 1195 | 777 | 69.1 | 925 | 77.4 |
| C | 549 | 305 | 55.6 | 326 | 59.0 |
| D | 1212 | 1155 | 95.3 | 1351 | 111.5 |
| E | 1385 | 537 | 38.8 | 774 | 55.9 |
| Avg. | | | 64.7 | | 76.0 |

**TABLE 2 Adhesion Testing Method C, Pull-Off Strength (*psi*)**

| Coating | Average | Repeatability Standard Deviation | Reproducibility Standard Deviation | Repeatability Limit | Reproducibility Limit |
|---|---|---|---|---|---|
| | $\bar{x}$ | sr | sR | r | R |
| B | 1974 | 261 | 324 | 732 | 907 |
| C | 1221 | 136 | 548 | 382 | 1535 |
| D | 2110 | 252 | 316 | 706 | 886 |
| E | 2012 | 239 | 359 | 669 | 1004 |

| Coating | Average | Repeatability Limit | | Reproducibility Limit | |
|---|---|---|---|---|---|
| | $\bar{x}$ | r | % of average | R | % of average |
| B | 1974 | 732 | 37.1 | 907 | 45.9 |
| C | 1221 | 382 | 31.3 | 1535 | 125.7 |
| D | 2110 | 706 | 33.5 | 886 | 42.0 |
| E | 2012 | 669 | 33.3 | 1004 | 49.9 |
| Avg. | | | 30.4 | | 70.5 |

**TABLE 3 Adhesion Testing Method D, Pull-Off Strength (*psi*)**

| Coating | Average | Repeatability Standard Deviation | Reproducibility Standard Deviation | Repeatability Limit | Reproducibility Limit |
|---|---|---|---|---|---|
| | $\bar{x}$ | sr | sR | r | SR |
| B | 2458 | 146 | 270 | 408 | 755 |
| C | 1232 | 31 | 116 | 87 | 324 |
| D | 2707 | 155 | 233 | 434 | 651 |
| E | 2354 | 163 | 273 | 456 | 764 |

| Coating | Average | Repeatability Limit | | Reproducibility Limit | |
|---|---|---|---|---|---|
| | $\bar{x}$ | r | % of average | R | % of average |
| B | 2458 | 408 | 16.6 | 755 | 30.7 |
| C | 1232 | 87 | 7.1 | 324 | 26.3 |
| D | 2707 | 434 | 16.0 | 651 | 24.0 |
| E | 2354 | 456 | 19.4 | 764 | 32.5 |
| Avg. | | | 14.8 | | 28.4 |

material; "*R*" is the interval representing the difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

10.1.2.1 Reproducibility limits are listed in Tables 1-5.

**TABLE 4 Adhesion Testing Method E, Pull-Off Strength (*psi*)**

| Coating | Average | Repeatability Standard Deviation | Reproducibility Standard Deviation | Repeatability Limit | Reproducibility Limit |
|---|---|---|---|---|---|
| | $\bar{x}$ | sr | sR | r | SR |
| B | 2210 | 173 | 215 | 483 | 601 |
| C | 1120 | 115 | 155 | 321 | 433 |
| D | 2481 | 361 | 422 | 1011 | 1181 |
| E | 2449 | 173 | 198 | 485 | 555 |

| Coating | Average | Repeatability Limit | | Reproducibility Limit | |
|---|---|---|---|---|---|
| | $\bar{x}$ | r | % of average | R | % of average |
| B | 2210 | 483 | 21.9 | 601 | 27.2 |
| C | 1120 | 321 | 28.7 | 433 | 38.7 |
| D | 2481 | 1011 | 40.7 | 1181 | 47.6 |
| E | 2449 | 485 | 19.8 | 555 | 22.7 |
| Avg. | | | 27.8 | | 34.1 |

**TABLE 5 Adhesion Testing Method F, Pull-Off Strength (*psi*)**

| Coating | Average | Repeatability Standard Deviation | Reproducibility Standard Deviation | Repeatability Limit | Reproducibility Limit |
|---|---|---|---|---|---|
| | $\bar{x}$ | sr | sR | r | SR |
| B | 2070 | 102 | 125 | 287 | 351 |
| C | 1106 | 60 | 108 | 169 | 304 |
| D | 2368 | 124 | 160 | 347 | 449 |
| E | 2327 | 217 | 237 | 609 | 664 |

| Coating | Average | Repeatability Limit | | Reproducibility Limit | |
|---|---|---|---|---|---|
| | $\bar{x}$ | r | % of average | R | % of average |
| B | 2070 | 287 | 13.9 | 351 | 17.0 |
| C | 1106 | 169 | 15.3 | 304 | 27.5 |
| D | 2368 | 347 | 14.7 | 449 | 19.0 |
| E | 2327 | 609 | 26.2 | 664 | 28.5 |
| Avg. | | | 17.5 | | 23.0 |

10.1.3 Any judgment in accordance with these two statements would have an approximate 95 % probability of being correct.

10.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method, therefore no statement is being made.

10.3 The precision statement was determined through statistical examination of 394 results, produced by analysts from seven laboratories, on four coatings, using five different instruments. Different coatings were used as a means to achieve a range of pull-off strengths covering the operating range of all the instruments.

10.3.1 Results obtained by the same operator using instruments from the same Method should be considered suspect if they differ in percent relative by more than the Intralaboratory values given in Table 6. Triplicate results obtained by different operators using instruments from the same Method should be considered suspect if they differ in percent relative by more than the Interlaboratory values given in Table 6.

## 11. Keywords

11.1 adhesion; coatings; field; metal substrates; paint; portable; pull-off strength; tensile test

**TABLE 6 Precision of Adhesion Pull-Off Measurements (averaged across coating types for each instrument)**

| Intralaboratory | Maximum Recommended Difference, % | Interlaboratory | Maximum Recommended Difference, % |
|---|---|---|---|
| Method B | 64.7 | Method B | 76.0 |
| Method C | 33.8 | Method C | 65.9 |
| Method D | 14.8 | Method D | 28.4 |
| Method E | 27.8 | Method E | 34.1 |
| Method F | 17.5 | Method F | 23.0 |

## ANNEXES

**(Mandatory Information)**

### A1. FIXED-ALIGNMENT ADHESION TESTER TYPE II (TEST METHOD B)

A1.1 *Apparatus:*

A1.1.1 This is a fixed-alignment portable tester, as shown in Fig. A1.1.[9,10]

NOTE A1.1—Precision data for Type II instruments shown in Table 6 were obtained using the devices described ed in Fig. A1.1.

A1.1.2 The tester is comprised of detachable aluminum loading fixtures having a flat conic base that is 20 mm (0.8 in.) in diameter on one end for securing to the coating, and a circular *T*-bolt head on the other end, a central grip for engaging the loading fixture that is forced away from a tripod base by the interaction of a hand wheel (or nut), and a coaxial bolt connected through a series of belleville washers, or springs in later models, that acts as both a torsion relief and a spring that displaces a dragging indicator with respect to a scale.

A1.1.3 The force is indicated by measuring the maximum spring displacement when loaded. Care should be taken to see that substrate bending does not influence its final position or the actual force delivered by the spring arrangement.

A1.1.4 The devices are available in four ranges: From 3.5, 7.0, 14, and 28 MPa (0 to 500, 0 to 1000, 0 to 2000, and 0 to 4000 psi).

A1.2 *Procedure:*

A1.2.1 Center the bearing ring on the coating surface concentric with the loading fixture. Turn the hand wheel or nut of the tester counterclockwise, lowering the grip so that it slips under the head of the loading fixture.

A1.2.2 Align or shim the three instrument swivel pads of the tripod base so that the instrument will pull perpendicularly to the surface at the bearing ring. The annular ring can be used on flexible substrates.

A1.2.3 Take up the slack between the various members and slide the dragging (force) indicator located on the tester to zero.

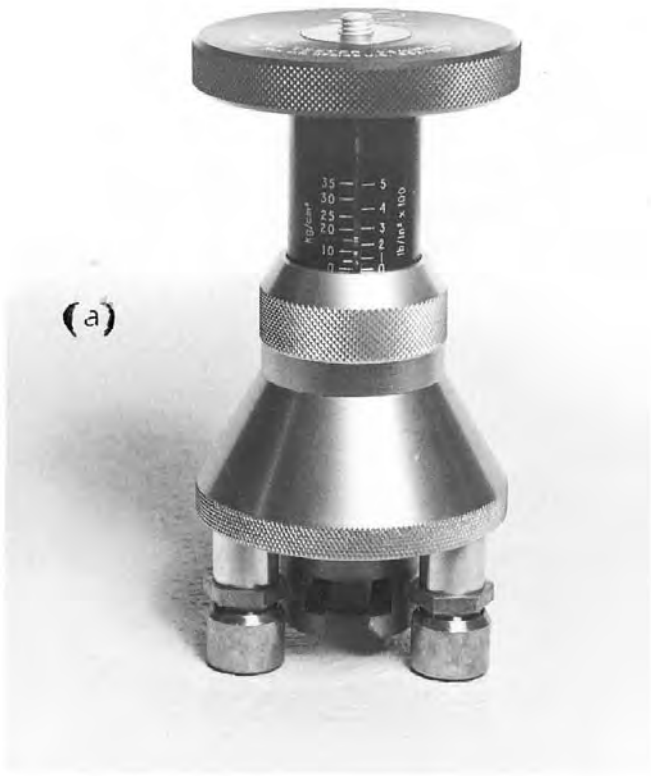
A1.2.4 Firmly hold the instrument with one hand. Do not allow the base to move or slide during the test. With the other hand, turn the hand wheel clockwise using as smooth and constant motion as possible. Do not jerk or exceed a stress rate of 150 psi/s (1 MPa/s) that is attained by allowing in excess of 7 s/7 MPa (7 s/1000 psi), stress. If the 14 or 28 MPa (2000 or 4000 psi) models are used, the hand wheel is replaced with a nut requiring a wrench for tightening. The wrench must be used in a plane parallel to the substrate so that the loading fixture will not be removed by a shearing force or misalignment, thus negating the results. The maximum stress must be reached within about 100 s.

A1.2.5 The pulling force applied to the loading fixture is increased to a maximum or until the system fails at its weakest locus. Upon failure, the scale will rise slightly, while the dragging indicator retains the apparent load. The apparatus scale indicates an approximate stress directly in pounds per square inch, but may be compared to a calibration curve.

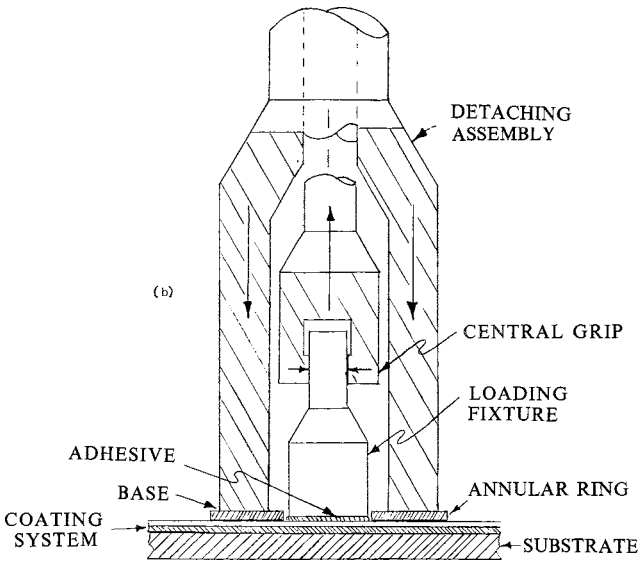
A1.2.6 Record the highest value attained by reading along the bottom of the dragging indicator.

[9] The sole source of supply of the Elcometer, Model 106, adhesion tester known to the committee at this time is Elcometer Instruments, Ltd., Edge Lane, Droylston, Manchester M35 6UB, United Kingdom, England.

[10] If you are aware of alternative suppliers, please provide this information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, [1]which you may attend




(a)




(b)

**FIG. A1.1 Photograph (a) and Schematic (b) of Type II, Fixed Alignment Pull-Off Tester**

## A2. SELF-ALIGNING ADHESION TESTER TYPE III (TEST METHOD C)

A2.1 *Apparatus:*

A2.1.1 This is a self-aligning tester, as shown in Fig. A2.1.[11,10]

NOTE A2.1—Precision data for Type III instruments shown in Table 6 were obtained using the devices described in Fig. A2.1.

A2.1.2 Load is applied through the center of the loading fixture by a hydraulic piston and pin. The diameter of the piston bore is sized so that the area of the bore is equal to the net area of the loading fixture. Therefore, the pressure reacted by the loading fixture is the same as the pressure in the bore and is transmitted directly to a pressure gauge.

A2.1.3 The apparatus is comprised of: a loading fixture, 19 mm (0.75 in.) outside diameter, 3 mm (0.125 in.) inside diameter, hydraulic piston and pin by which load is applied to the loading fixture, hose, pressure gauge, threaded plunger and handle.

A2.1.4 The force is indicated by the maximum hydraulic pressure as displayed on the gauge, since the effective areas of the piston bore and the loading fixture are the same.

A2.1.5 The testers are available in three standard working ranges: 0 to 10 MPa (0 to 1500 psi), 0 to 15 MPa (0 to 2250 psi), 0 to 20 MPa (0 to 3000 psi). Special loading fixtures shaped to test tubular sections are available.

A2.2 *Procedure:*

A2.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

A2.2.2 Insert a decreased TFE-fluorocarbon plug into the loading fixture until the tip protrudes from the surface of the loading fixture. When applying adhesive to the loading fixture, avoid getting adhesive on the plug. Remove plug after holding the loading fixture in place for 10 s.

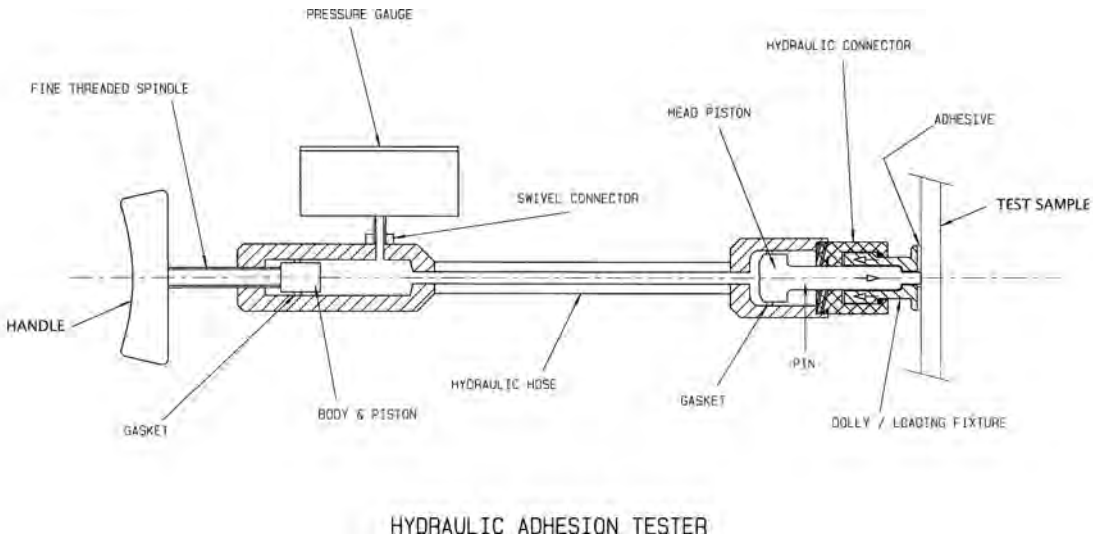
A2.2.3 Ensure that the black needle of the tester is reading zero. Connect a test loading fixture to the head and increase the pressure by turning the handle clockwise until the pin protrudes from the loading fixture. Decrease pressure to zero and remove the test loading fixture.

A2.2.4 Connect the head to the loading fixture to be tested, by pulling back the snap-on ring, pushing the head and releasing the snap-on ring. Ensure the tester is held normal to the surface to be tested and that the hose is straight.

A2.2.5 Increase the pressure slowly by turning the handle clockwise until either the maximum stress or failure is reached.

[11] The sole source of supply of the Hate Mark VII adhesion tester known to the committee at this time is Hydraulic Adhesion Test Equipment, Ltd., 629 Inlet Rd., North Palm Beach, FL 33408.

(a)




(b)

**FIG. A2.1 Photograph (a) and Schematic (b) of Type III, Self-Alignment Tester**

## A3. SELF-ALIGNMENT ADHESION TESTER TYPE IV (TEST METHOD D)

A3.1 *Apparatus:*

A3.1.1 This is a self-aligning automated tester, which may have a self-contained pressure source and has a control module that controls a choice of different load range detaching assemblies, or pistons. It is shown in Fig. A3.1.

NOTE A3.1—Precision data for Type IV instruments shown in Table 6 were obtained using the devices described in Fig. A3.1.

A3.1.2 The apparatus is comprised of: (*1*) a loading fixture, (*2*) a detaching assembly, or piston, (*3*) one of several control modules, and (*4*) a pressurized air source.

A3.1.3 The loading fixtures are available on many different sizes (3 to 75 mm) based on the particulars of the system being tested. The standard loading fixture is 12.5 mm (0.5 in) in diameter. The face of the loading fixture can be rough, smooth, curved, machined, etc.

A3.1.4 The pistons are also available in several different sizes, or load ranges. It is recommended that a piston is chosen so that the midpoint of the range is close to the suspected tensile strength of the coating to be tested. This will provide the most forgiveness in errors of assumed coating strength.

A3.1.5 Several models of control modules are available. The digital models may include optional accessories allowing for features such as wireless real-time transmission of pull-tests via Bluetooth and your PC, LabVIEW-created software, USB camera attachment to photo document your pulls, and computer generated reporting capabilities.

A3.1.6 The pressurized air source may be (*1*) a self-contained miniature air cylinder for maximum portability, (*2*) shop (bottled) air, or (*3*) air from an automated pump.

A3.2 *Procedure:*

A3.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to Type IV testers are described in the following section.

A3.2.2 Adhere a loading fixture to the coating based on the epoxy manufacturers instructions, employing either a cut-off ring or adhesive mask to reproducibly define the area being tested. On larger sized loading fixtures, simply wipe away excess epoxy with a cotton tipped applicator or rag.

A3.2.3 Place the piston over the loading fixture and gently thread the reaction plate (top of piston) onto the loading fixture.

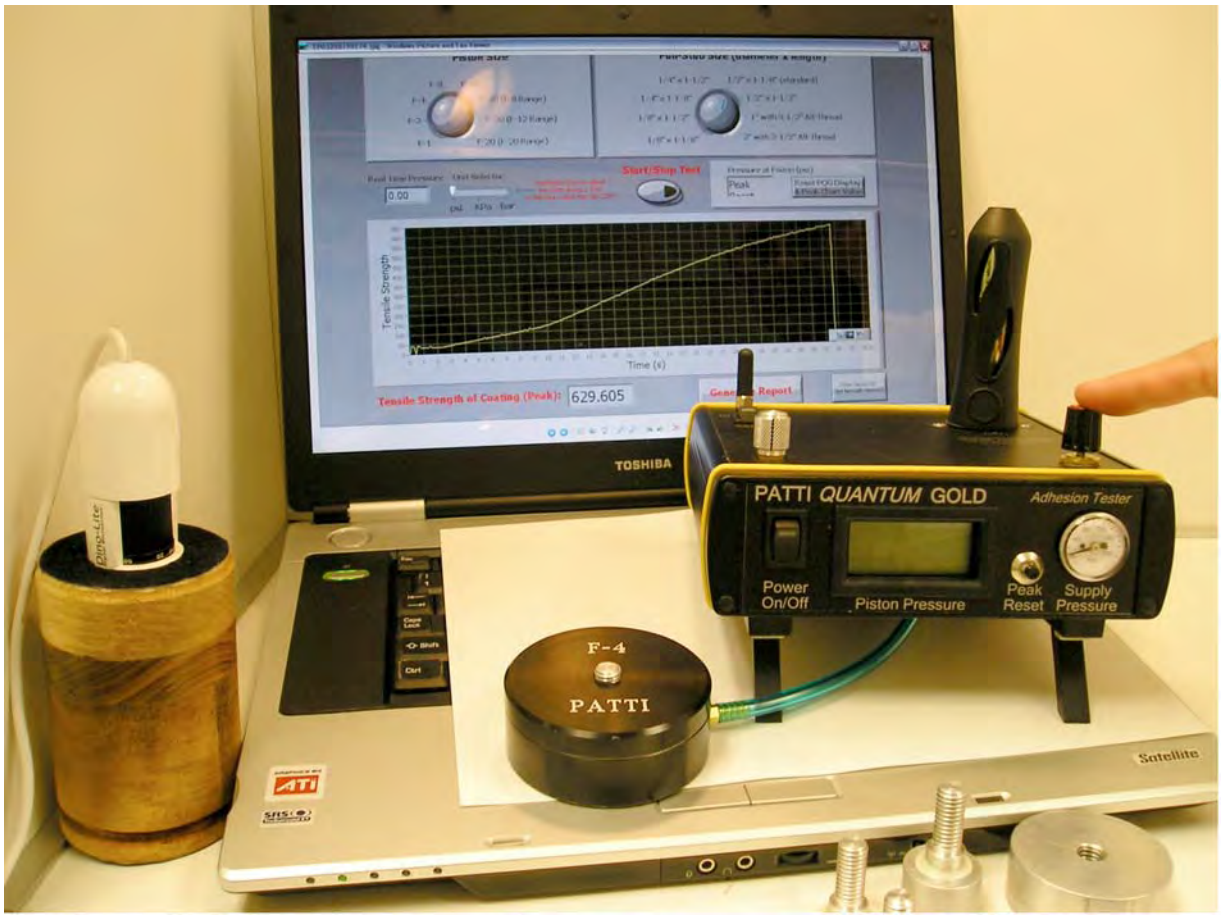
A3.2.4 Attach the appropriate pneumatic hoses and ensure that the control module has an air supply of at least 0.67 Mpa (100 psi) as read on the supply gauge. Zero the Piston Pressure gauge/display.

A3.2.5 Ensure that the Rate Valve is closed (clockwise finger tight) and then press and hold the Run button. Slowly open the Rate Valve (counterclockwise) and monitor the Piston Pressure gauge/display to obtain a rate of pressure increase of less than 1 MPa/s (100 psi/s) yet allowing for the entire test to be complete within 100 s. When the loading fixture detaches from the surface or the required pressure is attained, release the Run button.

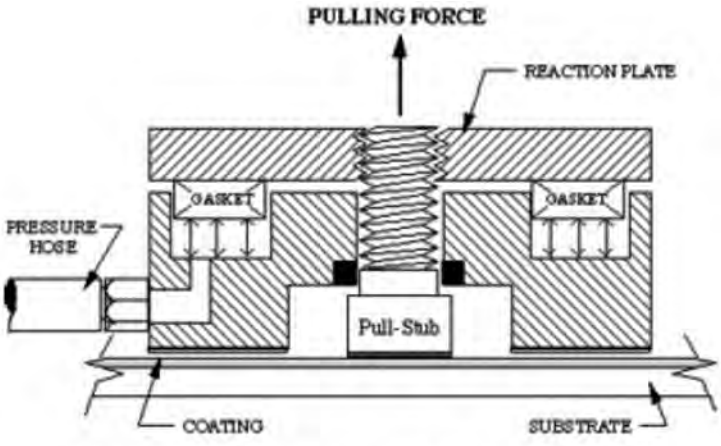
A3.2.6 Open the Rate Valve even further (counterclockwise) to relieve the residual pressure so the loading fixture can be removed from the piston to prepare for the next test.

A3.2.7 Record both the maximum pressure attained and the specific piston used. Convert the maximum Piston Pressure to coating tensile strength using the conversion charts or set the specific testing parameters within the software to have this step completed automatically.

A3.2.8 Photo document the test site if possible/necessary using the optional USB camera.




(a)




CROSS SECTION SCHEMATIC OF PISTON ATTACHED TO PULL-STUB

(b)

**FIG. A3.1 Photograph (a) and Schematic of Piston (b) of Type IV Self-Alignment Adhesion Tester**

## A4. SELF-ALIGNING ADHESION TESTER TYPE V (TEST METHOD E)

A4.1 *Apparatus:*

A4.1.1 This is a self-aligning tester, as shown in Fig. A4.1.[12,10]

NOTE A4.1—Precision data for Type V instruments shown in Table 6 were obtained using the devices described as "Manual" in Fig. A4.1.

A4.1.2 A self-aligning spherical loading fixture head is used by this tester. Load evenly distributes pulling force over the surface being tested, ensuring a perpendicular, balanced pull-off. The diameter of the standard loading fixture 20 mm (0.78 in.) is equal to the area of the position bore in the actuator. Therefore, the pressure reacted by the loading fixture is the same as the pressure in the actuator and is transmitted directly to the pressure gauge. The tester performs automatic conversion calculations for the 50 mm (1.97 in.) loading fixtures and common custom sizes 10 and 14 mm (0.39 in. and 0.55 in. respectively).

A4.1.3 The apparatus is comprised of: a loading fixture, 10 to 50 mm (0.39 and 1.97 in. respectively) diameter, hydraulic actuator by which the load is applied to the loading fixture, pressure gauge with LCD display, and hydraulic pump.

A4.1.4 The display on the pressure gauge indicates the maximum force and the rate of pull.

A4.1.5 The tester is available with accessories for finishes on plastics, metals, and wood. Special loading fixtures, typically 10 mm (0.39 in.) and 14 mm (0.55 in.) are available for use on curved surfaces and when higher pull-off pressures are required.

A4.2 *Procedure:*

A4.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to Type V Testers are described in this section.

A4.2.2 Ensure the pressure relief valve on the pump is completely open. Push the actuator handle completely down into the actuator assembly.

A4.2.3 Place the actuator assembly over the loading fixture head and attach the quick coupling to the loading fixture. Close the pressure relief valve on the pump. Select the appropriate loading fixture size on the display and then press the zero button.

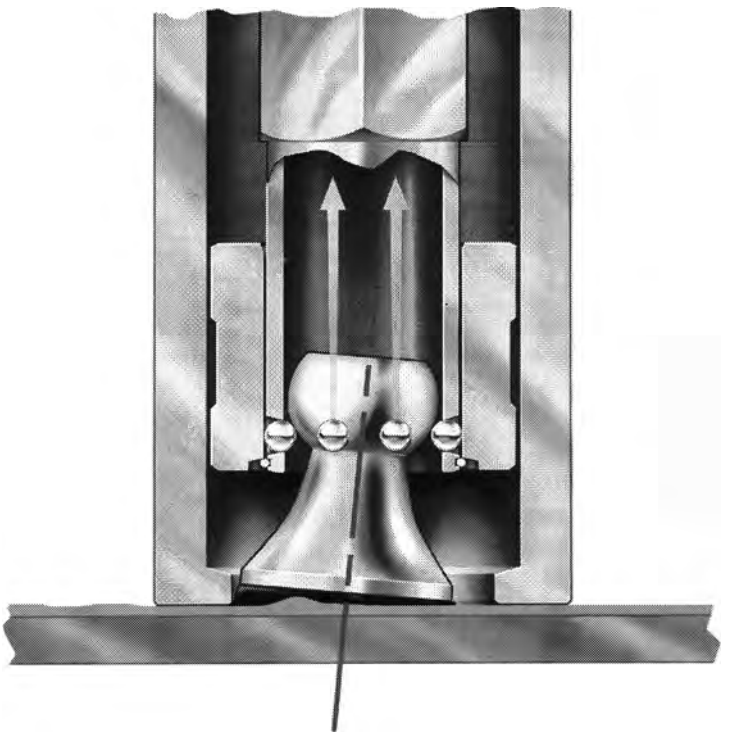
A4.2.4 Prime the pump by pumping the handle until the displayed reading approaches the priming pressure as explained in the instruction manual. Return the pump handle to its full upright position and then complete a single stroke at a uniform rate of no more than 1 MPa/s (150 psi/s) as shown on the display until the actuator pulls the loading fixture from the surface.

A4.2.5 Immediately following the pull, open the pressure relief valve on the pump to release the pressure. The display will maintain the maximum pressure reading. Record this pull off pressure into the tester's memory and mark the loading fixture for future qualitative analysis.

A4.2.6 A version of this tester is available with an automatic hydraulic pump.

[12] The sole source of supply of the PosiTest Pull-Off Tester known to the committee at this time is DeFelsko Corporation, 802 Proctor Avenue, Ogdensburg, NY 13669 USA.


(a)



(b)

**FIG. A4.1 Photograph (a) and Schematic (b) of Type V, Self-Aligning Tester**

## A5. SELF-ALIGNING ADHESION TESTER TYPE VI (TEST METHOD F)

A5.1 *Apparatus:*

A5.1.1 This is a self-aligning tester, as shown in Fig. A5.1.

NOTE A5.1—Precision data for Type VI instruments shown in Table 6 were obtained using the devices described in Fig. A5.1.

A5.1.2 The self-aligning testing head uses four independently operated feet to ensure that the pull stress on the loading fixture is evenly distributed independently of the shape of the substrate or the angle of the loading fixture to the surface. See Fig. A5.1

A5.1.3 The apparatus comprises a crank handle pull mechanism with a hydraulic cable mechanism, a self-aligning test head rated at 6.3 kN and loading fixtures.

A5.1.4 A range of loading fixtures, from 2.8 to 70 mm diameter is available. The 20 mm diameter loading fixtures are directly connected to the test head by means of a quick release connector. Other loading fixture sizes are supplied with threads machined to allow connection to the self-aligning test head using an adapter. Loading fixtures with diameters in the range 2.8 to 5.7 mm are used with a micro self-aligning test head rated at 1 kN.

A5.1.5 The force applied to the loading fixture is displayed on a hydraulic pressure gauge with a dragging indicator that shows the maximum reading at the point where the loading fixture is removed from the surface. The gauge carries both PSI and MPa values on two scales.

A5.2 *Procedure:*

A5.2.1 Following the general procedures described in Sections 6 and 7, procedures specific to Type VI testers are described in the following section.

A5.2.2 Ensure that the pressure in the pull mechanism is released by opening the valve at the bottom of the cylinder. Turn the dragging indicator to zero in line with the gauge indicator needle.

A5.2.3 Attach the self-aligning test head to the hydraulic cable mechanism using the quick release connector on the side of the test head. Return the crank handle to the start position and ensure that the four pistons of the self-aligning head are level by pushing the head against a flat surface.

A5.2.4 Place the relevant support ring over the loading fixture. A support ring is not required for 25 mm, 50 mm, or 70 mm diameter loading fixtures or for 50 mm square loading fixtures.

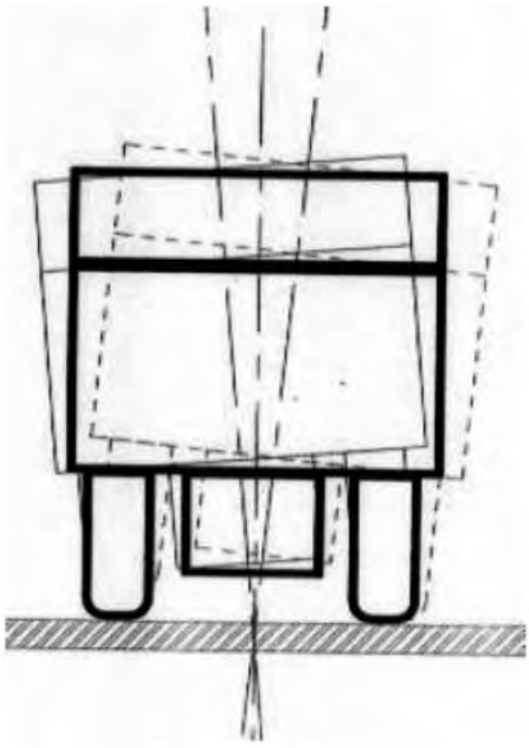
A5.2.5 Attach the test head to the loading fixture either directly or using the adapter, where appropriate. Close the valve.

A5.2.6 Ensure that the hydraulic cable mechanism is not pulled tight. Hold the pull mechanism in one hand and operate the crank with the other using a smooth and regular motion to ensure that the force is applied evenly until the desired value is reached or the fracture occurs.

A5.2.7 Immediately following the completion of the pull, open the valve to release any residual pressure and return the crank handle to the start position. The unit is now ready for the next pull.

A5.2.8 Note the value indicated by the dragging indicator and mark the loading fixture for further analysis as described in Section 8.

(a)



(b)

**FIG. A5.1 Photograph (a) and Schematic (b) of Type VI, Self-Aligning Tester**

## APPENDIX

**(Nonmandatory Information)**

### X1. STRESS CALCULATION

X1.1 The stress computed in 8.2 is equal to the uniform pull-off strength of the analogous rigid coating system if the applied force is distributed uniformly over the critical locus at the instant of failure. For any given continuous stress distribution where the peak-to-mean stress ratio is known, the uniform pull-off strength may be approximated as:

$$U = XR_o \quad \text{(X1.1)}$$

where:

- $U$ = uniform pull-off strength, representing the greatest force that could be applied to the given surface area, psi (MPa),
- $X$ = measured in situ pull-off strength calculated in 8.2, psi (MPa), and
- $R_o$ = peak-to-mean stress ratio for an aligned system.

It is important to note that a difference between these pull-off strengths does not necessarily constitute an error; rather the in-situ measurement simply reflects the actual character of the applied coating system with respect to the analogous ideal rigid system.

X1.2 An error is introduced if the alignment of the apparatus is not normal to the surface. An approximate correction by the peak-to-mean stress ratio is:

$$R = R_o(1 + 0.14\, az/d) \quad \text{(X1.2)}$$

where:

- $z$ = distance from the surface to the first gimbal or the point at which the force and counter force are generated by the action of the driving mechanism, in. (mm),
- $d$ = diameter of the loading fixture, in. (mm),
- $a$ = angle of misalignment, degrees (less than 5), and
- $R$ = maximum peak-to-mean stress ratio for the misaligned rigid system.

## SUMMARY OF CHANGES

Committee D01 has identified the location of selected changes to this standard since the last issue (D 4541 - 02) that may impact the use of this standard. (Approved February 1, 2009.)

(*1*) The scope was modified to describe the types of substrates covered by the test method.

(*2*) Test Method A was discontinued. Test Method F and Annex F were added.

(*3*) Section 10 — The precision and bias statement was revised based on the results of a new round-robin study.

(*4*) Editorial changes were made throughout the document.

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# LAMPIRAN VI

# ASTM D4417–03

## *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*

**Designation: D 4417 – 03**

# Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel[1]

This standard is issued under the fixed designation D 4417; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 These test methods cover the description of techniques for measuring the profile of abrasive blast cleaned surfaces in the laboratory, field, or in the fabricating shop. There are additional techniques suitable for laboratory use not covered by these test methods.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Summary of Test Method

2.1 The methods are:

2.1.1 *Method A*—The blasted surface is visually compared to standards prepared with various surface profile depths and the range determined.

2.1.2 *Method B*—The depth of profile is measured using a fine pointed probe at a number of locations and the arithmetic mean determined.

2.1.3 *Method C*—A composite plastic tape is impressed into the blast cleaned surface forming a reverse image of the profile, and the maximum peak to valley distance measured with a micrometer.

## 3. Significance and Use

3.1 The height of surface profile has been shown to be a factor in the performance of various coatings applied to steel. For this reason, surface profile should be measured prior to coating application to ensure that it meets that specified. The instruments described are readily portable and sufficiently sturdy for use in the field.

NOTE 1—Optical microscope methods serve as a referee method for surface profile measurement. Profile depth designations are based on the concept of mean maximum profile ( $\bar{h}$ max); this value is determined by averaging a given number (usually 20) of the highest peak to lowest valley measurements made in the field of view of a standard measuring microscope. This is done because of evidence that coatings performance in any one small area is primarily influenced by the highest surface features in that area and not by the average roughness.[2]

## 4. Apparatus

4.1 *Method A*—A profile comparator consisting of a number of areas (each approximately one square inch in size), usually side by side, with a different profile or anchor pattern depth. Each area is marked giving the nominal profile depth in mils or micrometres. Typical comparator surfaces are prepared with steel shot, steel grit, or sand or other nonmetallic abrasive, since the appearance of the profile created by these abrasives may differ. The comparator areas are used with or without magnification of 5 to 10 power.

4.2 *Method B*—A dial gage[3] depth micrometer fitted with a pointed probe. The probe is machined at a 60° angle with a nominal radius of 50 µm. The base of the instrument rests on the tops of the peaks of the surface profile while the spring loaded tip projects into the valleys.

4.3 *Method C*—A special tape[4] containing a compressible foam attached to a noncompressible uniform plastic film. A burnishing tool is used to impress the foam face of the tape into the surface to create a reverse replica of the profile that is measured using a spring-loaded micrometer.

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[1] These test methods are under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.46 on Industrial Protective Coatings.

Current edition approved May 10, 2003. Published June 2003. Originally approved in 1984. Last previous edition approved in 1999 as D 4417 – 93 (1999).

[2] John D. Keane, Joseph A. Bruno, Jr., Raymond E. F. Weaver, "Surface Profile for Anti-Corrosion Paints," Oct. 25, 1976, Steel Structures Painting Council, 4400 Fifth Ave., Pittsburgh, PA 15213.

[3] The sole source of supply of suitable depth micrometers known to the committee at this time is the surface profile gage, Model 123, Elcometer Instruments, Ltd., Edge Lane, Droylston, Manchester M35 6UB, United Kingdom, England. If you are aware of alternative suppliers, please proved this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[4] The sole source of supply of suitable replica tape, Press-O-Film, known to the committee at this time is Testex. 8 Fox Lane, Newark, DE 19711. If you are aware of alternative suppliers, please proved this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend

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## 5. Test Specimens

5.1 Use any metal surface that, after blast cleaning, is free of loose surface interference material, dirt, dust, and abrasive residue.

## 6. Procedure

6.1 *Method A*:

6.1.1 Select the comparator standard appropriate for the abrasive used for blast cleaning.

6.1.2 Place the comparator standard directly on the surface to be measured and compare the roughness of the prepared surface with the roughness on the comparator segments. This can be done with the unaided eye, under 5 to 10 power magnification, or by touch. When using magnification, the magnifier should be brought into intimate contact with the standard, and the depth of focus must be sufficient for the standard and surface to be in focus simultaneously.

6.1.3 Select the comparator segment that most closely approximates the roughness of the surface being evaluated or, if necessary, the two segments to which it is intermediate.

6.1.4 Evaluate the roughness at a sufficient number of locations to characterize the surface as specified or agreed upon between the interested parties. Report the range of results from all locations as the surface profile.

6.2 *Method B*:

6.2.1 Prior to use set the gage to zero by placing it on a piece of plate float glass. Hold the gage by its base and press firmly against the glass. Adjust the instrument to zero.

6.2.2 To take readings, hold the gage firmly against the prepared substrate. Do not drag the instrument across the surface between readings, or the spring-loaded tip may become rounded leading to false readings.

6.2.3 Measure the profile at a sufficient number of locations to characterize the surface, as specified or agreed upon between the interested parties. At each location make ten readings and determine the mean. Then determine the mean for all the locations and report it as the profile of the surface.

6.3 *Method C*:

6.3.1 Select the correct tape range for the profile to be measured: coarse, 0 to 50 µm (0 to 2 mils) and extra coarse, 40 to 115 µm (1.5 to 4.5 mils).

6.3.2 Remove the wax paper backing and place the tape on the prepared surface with the foam side down, that is, put the dull side down.

6.3.3 Hold the tape firmly on the surface and rub the circular cut-out portion (approximately 6.5 mm (⅜ in.) diameter) with the burnishing tool until a uniform gray color appears.

6.3.4 Remove the tape and place it between the anvils of a spring-loaded micrometer. Measure the thickness of the tape (compressed foam and non-compressible plastic film combined). Subtract the thickness of the noncompressible plastic film to obtain the surface profile.

6.3.5 Measure the profile at a sufficient number of locations to characterize the surface, as specified or agreed upon between the interested parties. At each location make three readings and determine the mean. Then determine the mean for all the locations and report it as the profile of the surface.

## 7. Report

7.1 Report the range and the appropriate average (mean or mode) of the determinations, the number of locations measured, and the approximate total area covered.

## 8. Precision and Bias

8.1 *Test Method A*:

8.1.1 *Applicability*—Based on measurements of profiles on surfaces of 8 steel panels, each blast cleaned with 1 of 8 different abrasives to a white metal degree of cleaning, having known ratings of profile height ranging from 37 µm (1.5 mils) to 135 µm (5.4 mils), the correlation coefficient for Test Method A was found to be 0.75 and the coefficient of determination was found to be 0.54.

8.1.2 *Precision*—In an interlaboratory study of Test Method A in which 2 operators each running 2 tests on separate days in each of 6 laboratories tested 8 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 20 % with 141 df and the interlaboratory coefficient was found to be 19 % with 40 df, after rejecting 3 results for one time because the range between repeats differed significantly from all other ranges. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

8.1.2.1 *Repeatability*—Two results, each the mean of four replicates, obtained by the same operator should be considered suspect if they differ by more than 56 %.

8.1.2.2 *Reproducibility*—Two results, each the mean of four replicates, obtained by operators in different laboratories should be considered suspect if they differ by more than 54 %.

8.2 *Test Method B*:

8.2.1 *Applicability*—Based on measurements of profiles on surfaces of 8 steel panels, each blast cleaned with 1 of 8 different abrasives to a white metal degree of cleaning, having known ratings of profile height ranging from 1.5 mils (37 µm) to 5.4 mils (135 µm), the correlation coefficient for Test Method B was found to be 0.99 and the coefficient of determination was found to be 0.93.

8.2.2 *Precision*—In an interlaboratory study of Test Method B in which 2 operators, each running 2 tests on separate days, in each of 5 laboratories tested 8 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 19 % with 113 df and the interlaboratory coefficient was found to be 28 % with 32 df, after rejecting 3 results for one time because the range between repeats differed significantly from all other ranges. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

8.2.2.1 *Repeatability*—Two results, each the mean of four replicates, obtained by the same operator should be considered suspect if they differ by more than 54 %.

8.2.2.2 *Reproducibility*—Two results, each the mean of four replicates, obtained by operators in different laboratories should be considered suspect if they differ by more than 79 %.

8.3 *Method C (X-Coarse Tape)*:

8.3.1 *Applicability*—Based on measurements of profiles on surfaces of 8 steel panels, each blast cleaned with 1 of 8 different abrasives to a white metal degree of cleaning, having known ratings of profile height ranging from 37 µm (1.5 mils) to 135 µm (5.4 mils), the correlation coefficient for Test Method C (X-Coarse Tape) was found to be 0.96 and the coefficient of determination was found to be 0.93.

8.3.2 *Precision*—In an interlaboratory study of Test Method C (X-Coarse Tape) in which 2 operators each running 2 tests on separate days in each of 6 laboratories tested 8 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 9 % with 120 df and the interlaboratory coefficient 13 % with 32 df. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

8.3.2.1 *Repeatability*—Two results, each the mean of four replicates, obtained by the same operator should be considered suspect if they differ by more than 25 %.

8.3.2.2 *Reproducibility*—Two results, each the mean of four replicates, obtained by operators in different laboratories should be considered suspect if they differ by more than 37 %.

8.4 *Test Method C (Coarse Tape)*:

8.4.1 *Applicability*—Based on measurements of profiles on surfaces of 6 steel panels, each blast cleaned with 1 of 6 different abrasives to a white metal degree of cleaning, having known ratings of profile height ranging from 37 µm (1.5 mils ) to 57 µm (2.3 mils), the correlation coefficient for Test Method C (Coarse Tape) was found to be 0.48 and the coefficient of determination was found to be 0.23.

8.4.2 *Precision*—In an interlaboratory study of Test Method C (Coarse Tape) in which 2 operators each running 2 tests on separate days in each of 5 laboratories tested 6 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 11 % with 90 df and the interlaboratory coefficient 11 % with 24 df. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

8.4.2.1 *Repeatability*—Two results, each the mean of four replicates, obtained by the same operator should be considered suspect if they differ by more than 30 %.

8.4.2.2 *Reproducibility*—Two results, each the mean of four replicates, obtained by operators in different laboratories should be considered suspect if they differ by more than 28 %.

8.5 *Test Method C ("Paint" Grade Tape)*:

8.5.1 *Applicability*—Based on measurement of profiles of surfaces of 5 steel panels, each blast cleaned with one of five different abrasives to a white metal degree of cleaning having known (stylus surface roughness measured) ratings of profile height ranging from 1.5 mils to 3.0 mils, the correlation coefficient for Test Method C ("Paint" Grade tape) was found to be 0.92 and the coefficient of determination was found to be 0.85.

8.5.2 *Precision*—In an interlaboratory study of Test Method C ("Paint" Grade tape) in which operators in each of 7 laboratories tested 5 surfaces with a broad range of profile characteristics and levels, the intralaboratory coefficient of variation was found to be 9 % with 150 df and the interlaboratory coefficient 10 % with 25 df. Based on these coefficients, the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results.

8.5.2.1 *Repeatability*—Two results, each the mean of 4 replicates, obtained by the same operator, should be considered suspect (2 standard deviations) if they differ by more than 18 %.

8.5.2.2 *Reproducibility*—Two results, each the mean of 4 replicates, obtained by operators in different laboratories, should be considered suspect (2 standard deviations) if they differ by more than 22 %.

8.6 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in these test methods for measuring surface profile, bias cannot be determined.

NOTE 2—The test methods measure different values and the qualitative rating on which the applicability was determined also measures a different value. The mode is determined with the comparator of Test Method A. The height of a single valley below a plane at the level of the highest surrounding peaks is measured with the fine pointed probe of Test Method B. The distance from the bottoms of many of the deepest valleys to the tops of the highest peaks (maximum profiles) are measured with the composite plastic of Test Method C. The height of a single peak above an adjacent valley below is measured with a microscope for the qualitative rating that is compared with each of the methods in correlation calculations. Because the results for the microscope and for the fine pointed probe are measurements to an individual valley, the readings range over much broader limits than the results of the tape or the comparator.

## 9. Keywords

9.1 abrasive; abrasive blast cleaning; anchor pattern; surface profile; surface roughness

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# BIODATA PENULIS

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Penulis bernama **Moch Farid Azis**, seorang laki-laki kelahiran Sragen, 6 Juni 1995, merupakan anak keenam dari tujuh bersaudara. Kedua orang tua penulis bernama Achmadi Achmad dan Siti Musarofah tinggal di Sragen Dok, Sragen Wetan, Sragen, Jawa Tengah. Penulis telah menempuh pendidikan sejak kecil dimulai dari TK Siwi Peni II Sragen (tahun 1999-2001), SD Negeri Sragen 1 (tahun 2001-2007), SMP Negeri 2 Sragen (tahun 2007-2010), dan SMA Negeri 1 Sragen (2010-2013), hingga akhirnya berkesempatan menempuh pendidikan perkuliahan di Institut Teknologi Sepuluh Nopember (ITS) Surabaya pada program studi S-1 Departemen Teknik Kelautan, Fakultas Teknologi Kelautan.

Selama berkuliah di Institut Teknologi Sepuluh Nopember (ITS) Surabaya, penulis pernah aktif di kegiatan kemahasiswaan, di antaranya Unit Kegiatan Pramuka ITS Gudep 611 dan Lembaga Dakwah Jurusan (LDJ) Bahrul ‘Ilmi Teknik Kelautan. Di luar kampus, penulis juga aktif dalam perkumpulan mahasiswa daerah yang bernama Keluarga Mahasiswa Sragen (KMS). Kegemaran penulis mengikuti forum-forum ilmiah dan lomba Program Kreatifitas Mahasiswa membawa penulis mendapat juara 2 pada Lomba GT Ocean 2016 yang diadakan oleh Himpunan Mahasiswa Teknik Kelautan (Himatekla), FTK, ITS, masuk dalam finalis 10 besar Lomba PKM-GT.COM tingkat institut yang diadakan oleh Klub Keilmiahan ITS, dan mendapat hibah dana dari lomba PKM Gagasan Tertulis tingkat nasional yang diadakan oleh Kementerian Riset Teknologi dan Pendidikan Tinggi (Ristekdikti). Termotivasi jiwa wirausaha orang tua penulis, sejak di bangku SLTA hingga saat ini penulis memiliki minat yang sangat tinggi di dunia bisnis.